CHAPTER 5

EXPERIMENTAL RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

The present study is an attempt to undertake a systematic study the 1/f noise in thin films of certain metals and semiconductors (as a function of temperature). This work requires a thorough search of similar works in literature. A brief review of the 1/f noise studies in thin films is quite essential. We attempted to formulate a chronological table pertaining to such studies of recent years. The references so found are presented in the form of a Table 5.1. This table pertains to the study of 1/f noise in thin films of metals, semiconductors and other connected materials. Table 5.1 appears to be more convenient for discussion of 1/f noise studies. We have purposefully excluded several of the 1/f noise studies pertaining to thin film squid devices and semiconductor devices that may contain semiconductor and metal thin films.

Innumerable references are surfed when '1/f noise in thin films' is searched on the internet. The surfed references are enclosed in a floppy, appended to the backside inner cover of this dissertation. Many cites could not be accessed as they appear to contain 'unsafe material' for our PC. We have selected a few references that are safe and chalked out over sixty references that are listed in Table 5.1. A brief review of the 1/f noise in metals, semiconductors and other materials are presented in following sections.

5.1.1 REVIEW OF RECENT 1/f NOISE STUDIES IN METALLIC FILMS

Thin films of uniform thickness, as described in Chapter 2, are grown. Several workers studied the physical properties of thin films. The following studies are of good value in the field of 1/f noise studies in metals. Hooge & Hoppenbrouwers [1] studied the “1/f noise of continuous thin gold films” and concluded that 1/f noise is inversely proportional to the total number of electrons. Tunaley [3] investigated 1/f noise in thin metallic films and showed that “1/f noise in thin films can be explained by the conduction that takes place by a tunneling mechanism between small islands of conductivity that usually form in thin films”. Eberhard and Horn [4] studied temperature dependence of 1/f noise in silver and gold thin films and found
that the magnitude of the noise increases rapidly with temperature in the range 90-350K. Takagi Keiji, Toru Mizunami & Satoshi Masuda [8] studied the 1/f noise in thin films of semi-continuous metal films. A higher deposition rate resulted in formation of smaller diameter and narrow necks between grains. Similarly low deposition rates and lower thickness of films (high resistance films) generate large diameter and wide-gap grains that may result into higher 1/f noise (powers). The authors hence studied films of grown under the TWO specific categories. The 1/f noise of gold and aluminum films increases in proportion to the fifth power of resistance in the high resistance range and to the cube of the resistance in the low resistance range. Rodbell & Ficalora [10] found that the presence of hydrogen altered the electrical properties of gold, titanium and tungsten thin films. Micro structural effects on the 1/f noise of thin aluminium films were studied and concluded that electro migration induced failures in interconnects with bimodal grain size distributions. Liou, Gong & Chen [19] studied electro migration effect on low frequency noise in aluminium thin films. The change observed in the noise spectrum was used to characterize the electro migration damage in the thin-film resistors. Yang-Wiyi & Celik-Butler-Zeynep [20] introduced a model to explain 1/f noise. Through this model the shape of the experimentally observed low-frequency spectra, the current dependence of the noise magnitude and the frequency exponent $\gamma$, as well as the temperature dependence of $\gamma$ can be explained.

Celik Butler Zeynep & Ye-Min [22] studied thin films of tungsten and alloys of aluminium-copper layers. The studies were meant to verify the prediction of electromigration failure due to metallisations by 1/f noise measurements. The so called mean-time-to-failure (MTF) and low-frequency noise-magnitude and spectral shape observed in these thin films were correlated. Bulashenko, Kochelap and Kochelap (VA) [25] studied noise redistribution in thin films due to electron scattering at the boundaries. It was observed that the noise redistributes towards higher frequencies by diminishing film thickness and decreasing surface specularity. The noise spectral density for a thin film is not Lorentzian unlike that for an unbounded sample.

Cottle [28] tried to interpret the current induced noise in thin films for implementing the results in the interconnection used in ULSI/VLSI devices. Importance of maintaining waveform stationarity when using 1/f$^2$ noise to detect electromigration is illustrated. In addition, non-stationary waveforms, associated with thin films with high degrees of stress are reported.
Rodbell Kenneth, Filter William, Frost Harold & Paul studied the power spectra of current noise [29] of the form $f^v$. It has been observed for some years in carbon composition resistors nerve tissues some semiconductor and metallic films, $f$ is the frequency and $v$ a constant closed to unity over many decades. It is established that noise signals are non-stationary in that the local means and variances change with time. This would seem to exclude the standard Weiner-Khinchine (W-K) theoretical approach since the mean auto correlation function is likely to become unbounded over an infinite interval. It is evident that a new definition of spectrum other than (W-K) type, is required and this has been discussed by Mandelbrot, who provides a method by which a $1/f$ noise spectrum may be predicted. However Mandelbrot’s spectrum is based on the notion of conditional probabilities and this might be interpreted as implying a knowledge of future in the present study the idea of spectrum is examined from a different viewpoint and it can easily be seen that rather than time averages as in (W-K) method, ensemble averages must be employed; the Ergordic theorem does not apply to non-stationary case. This lead rather directly to a formulation for the spectrum which is essentially same as that derived by Mandelbrot for the stochastic model of thin films.

Briggmann, Dagge, Frank, Seeger, Stoll & Verbruggen [32] studied irradiation-induced defects in thin aluminium films resulting into $1/f$ noise. The temperature dependence and annealing behaviour of the $1/f$ noise was interpreted in terms of annealing behaviour of the $1/f$ noise was understood in terms of thermally activated motion of defects in a distorted lattice potential. The noise in a thin metallic and semiconductor films are investigated because of its relative simplicity. These films consist of a collection of small islands in close proximity and it is suggested that the current flows in pulses as the carriers performs jumps between islands. Because of displacement current any jump will cause a current in the external circuit. If the islands are closed together a tunnelling mechanism will be involved and if the mean spacing between the islands is sufficiently large a $1/f$ type of spectrum can be produced.

The films are grown [32] on a substrate on which are scattered nuclei. Metal is deposited around the nuclei so that the final film can have a granular structure provided it is sufficiently thin. Electron or holes will travel through such a structure by means jumps between grains, and if the gaps between grains are only few angstrom units wide, the predominant process will be tunneling. It was assumed that the conduction electrons or holes are
nondegenerate and non-interacting. The noise spectrum $S(f)$ of thin metal film may be described as

$$S(f) = 4kTR + C / f^\gamma$$

(5.1)

Where the first term is the thermal noise, the second term is low frequency noise, $C$ is a sample dependent constant, $f$ is the frequency and $\gamma$ is constant around 1 or 2 and depends on the noise mechanism. It is reported that when bias current of the metal film is low, the noise will show $1/f$ type spectrum, but when bias current is increased to higher level the noise will show a $1/f'$ type spectrum where $\gamma$ may be greater than 2.

It is very important to identify [32] the quantity that is directly associated with $1/f$ noise in physical system. For example in homogeneous semiconductors the prime source of $1/f$ noise generation has been identified to be the variation of $n_0$ of free electrons, generation recombination mechanism (GR), variations in mobility, conductivity and such other functions of homogeneous semiconductors are the prime source $1/f$ noise.

Massiha [33] studied the excess electrical noise in aluminium in thin films and tried to characterize the films in terms of noise. Magnitude and frequency exponent for excess electrical noise spectra of $1/f$ were measured as a function of film temperature. Dagge, Frank, Seeger & Stoll [36] studied $1/f$ noise as an early indicator of electromigration damage in thin metal films. It was established that $1/f$ noise indicated an early VLSI damage. Dagge, Briggmann, Reuter, Seeger and Stoll [38]. Dagge [43] established that electromigration caused damage and resulted in $1/f$ noise in thin aluminium films. Vandamme & Van Kemenade [47] showed that $1/f$ noise measurements can be used as a fast non-destructive technique for reliability testing of LSI aluminium interconnects. They also estimated the damage due to electromigration. The stepwise increase in noise was attributed to the creation of highly mobile defects, which do not contribute significantly to resistance. Pennetta, Gingl, Kiss & Reggiani [51] considered the Nyquist sources and simulated the excess $1/f$ noise in thin film resistors.

The important studies (mentioned as bench mark papers) pertaining to metallic thin films as described in Sec 5.1.1, semiconductor thin films as briefed in Sec 5.1.2 and other studies pertaining to materials of implied importance as cited in Sec 5.1.3 are tabulated in the Table 5.1.
5.1.2 REVIEW OF RECENT 1/f NOISE STUDIES IN SEMICONDUCTOR FILMS

The systematic studies in semiconductor thin films were sparingly undertaken. This may be due to the fact it is rather difficult to grow thin films of a specific doping. The second difficulty is regarding the controlling of ambient conditions of semiconductors. However, electronic devices are good and reliable substitutes for semiconductor thin films. Saleem [67, Jilani [68] have studied the 1/f nature of MOSFETs and several semiconductor devices. The meagre works pertaining to 1/f noise in thin films of semiconductors are presented in the following section.

Jones & Mzunzu [11] investigated the 1/f noise in polycrystalline silicon. Khera, Kakalios, Wang & Iwaniczko [45] studied 1/f noise and thermal equilibration effects in amorphous silicon. 1/f noise and thermal equilibration effects in hot wire deposited amorphous silicon. Ho & Surya Charles [48] studied 1/f noise in hydrogenated amorphous silicon thin films. The experimental data provide strong evidence that the flicker noise originates from hydrogen motion within the material. The process appears to cause fluctuations in the device conductance by modulating the percolation path of the carriers. Ho & Surya Charles [50] studied the motion of hydrogen and 1/f noise in hydrogen amorphous silicon thin films. The experimental data provide strong evidence that the flicker noise originates from hydrogen motion within the material, the process appears to cause fluctuations in the device conductance by modulating the percolation path of the carriers.

Angelis, Dimitriadis, Brini, Kamarinos, Gueorguiev & Ivanov [59] studied the low-frequency noise spectroscopy of polycrystalline silicon thin-film transistors. The 1/f noise is explained with an existing model developed for monocrystalline silicon based on fluctuations of the inversion charge near the silicon-oxide interface. The Lorentzian spectrum is explained by fluctuations of the grain boundary interface charge with a model based on Gaussian distribution of the potential barriers over the grain boundary plane. Chen, Salm, Hooge & Woerlee [60] studied 1/f noise in polycrystalline SiGe analyzed in terms of mobility fluctuations. It is found that the 1/f noise parameter alpha decreases with increasing mobility, which does not agree with the parameter as measured in crystalline semiconductor material grown by molecular beam epitaxy. Tassis, Dimitriadis, Polychroniadis, Brini & Kamarinos studied the structural and trap properties of polycrystalline semiconducting FeSi2 thin films.
The power spectral density of the current fluctuations shows a $1/f$ prime (with gamma greater than 1) behaviour and is proportional to $1^\beta$ (with $\beta$ less than 2).

5.2 Review of Recent $1/f$ Noise Studies in Thin Films of Implied Importance:

Various workers have adopted the $1/f$ noise studies for varied applications [1-68]. In section 5.1.1 and 5.1.2 the studies pertaining to metals and semiconductors are reviewed. As pointed out already a large number of applications are found in literature, that are excluded in this review. From Table 5.1 it can be found that several workers have adopted $1/f$ noise studies to characterize the properties of superconductors and high temperature superconductors [12, 21, 23, 24, 26, 27, 30, 37, 61, 62 and 64]. The details pertaining to individual references are presented in Table 5.1.

The "$1/f$ noise behaviour of" mylar thin films [2], granular metal-insulator composites [7], $1/f$ like photo-noise effects in thin films [9], IR detectors [18] and electron-scattering [25] has been investigated. Material reliability in microelectronics [29], sputtering effects [31], excess noise generated in resistors [34], magnetic domain structure in Ni-Fe [39], microscopic mechanism in Co-Si structures [40] have been studied with an emphasis on $1/f$ noise. The $1/f$ noise behaviour in varied topics such as different types of resistors [42], SAW (surface acoustic waves properties) devices [44], thin bamboo structures [49], granular & thin film resistors [51, 56], MOSFETS [54, 68], physical systems [67], optical properties in ZnS & CdS [58] squid devices [65] have been investigated.

The present work is an attempt to study the metallic thin films and semi-conductor thin films maintained at different temperatures using a DSP system based on PC interface of 32 bit multimedia sound card.

5.3 THIN FILMS INVESTIGATED IN THE PRESENT STUDY

In the present study we have opted certain metallic and semiconductor thin films for $1/f$ noise studies. The details of the films are provided in the following paragraphs:

METALLIC THIN FILMS:

(i) Aluminium (Al)
(ii) Gold (Au)
(iii) Silver (Ag).
SEMI CONDUCTOR THIN FILMS:
(i) Copper Selenide (Cu$_2$Se)
(ii) Cadmium Selenide (CdSe)
(iii) Tellurium (Te)

In metals, dependence of 1/f noise on the thickness of the film and the effect of current densities on 1/f noise has been investigated. In semiconductor thin films the dependence of 1/f noise on thickness of the film and current densities have been investigated. The films were maintained at different temperatures and the effect of temperature on 1/f noise is investigated. For one semiconductor material the thin films of similar thickness were grown at different substrate temperatures. The films so grown may have different microstructure and formation [8]. The 1/f noise measurements in these films are likely to indicate the structural properties.

The details of films grown are given in Table 5.2. we prepared thin films of various resistance or thickness, by maintaining the substrate at different temperatures at the time of film growth for semiconductor films. Care has been taken to maintain same physical environment like vacuum and rate of deposition for same type of materials. Metallic films were deposited at 4x10$^{-6}$ mbar vacuum and at 2.4 A$^0$s$^{-1}$ deposition rate and while the semiconductor films were deposited at 2x10$^{-5}$ mbar vacuum and at 10A$^0$s$^{-1}$ deposition rate.

5.4 BIASING OF THIN FILMS AND ISOLATION

Silver paste was used to make the electrical connections to the thin film samples. Care is taken to make electrical connections as described in Chapter 4. Maintenance free rechargeable lead-acid accumulators of 6 V (40 VA hour rating) are used to DC biases the films. The batteries are regularly charged, while in usage. After every charging cycle batteries are conditioned by connecting a discharging resistance that bleeds about 20 mA continuously for about 30 minutes. Only the conditioned batteries are used to bias the film under test. Similar conditioned batteries are used to maintain the wide-band amplifier used to amplify the noise resulted from the DUT for further recording. Various workers [78] adopted similar DC biasing schemes, with slight variations, for 1/f noise studies as found in several of the references cited in Table 5.1. It has been observed that, for accurate measurements of 1/f noise (that can also be reproduced under equivalent conditions), the maintenance and conditioning of biasing accumulators plays an important role. Several earlier workers have dealt in length regarding the
types of power supplies to be used. It has been concluded that it is best to use the conditioned alkali or acid accumulators that are stable and of good quality (with minimum internal noise etc). Many investigators have put forward guidelines, similar to those presented in this study.

The DUT, amplifier, batteries and all biasing circuits are enclosed in grounded metallic enclosure to ensure minimum interference from the extraneous noise sources. Any interconnections between internal units and external units are made using low loss shielded cables. The PC, DVM, oscilloscope and other equipments are powered using AC regulators after passing through 50 Hz line filter. It is ensured that proper electrical grounding is made and the electrical neutral line is at a potential lesser than the recommended value of 0.2 V. Any improper connection, snapping of ground or bad electrical contact would result into fairly high noise at the output, hence the fault is easily detected. Complete details of the set up are furnished elsewhere [67, 68].

5.5 EXPERIMENTAL PROCEDURE

After taking all necessary precautions to eliminate any extraneous noise the film (DUT) is connected in the circuit and entire system is closed and is allowed to stabilize for some duration before recording the noise. of the film using PC. While recording the noise care is taken and DVM and CRO probes were removed from the system to avoid extraneous noise, similarly when temperature studies were carried out the film under test is allowed attain the required temperature and is placed in it for 10 minutes to attain stability. Power to the furnace is stopped automatically just before taking the reading to avoid AC interference.

Noise is recorded directly by connecting output of the amplifier of the system to microphone input line of sound card with proper signal conditioning to avoid saturation of the signal recorded. Noise is recorded for a period about 1 minute so that low frequency components can also be detected. However, our sound card can record noise between 10 Hz to 20 Hz under the non-linear amplification range, since the sound card has been designed for the range 20Hz to 45kHz. Low frequency components of less than 20 Hz do not represent a true behaviour, and have no significance as such.

Recorded noise is saved as individual *.WAV files in sequence with appropriate file name so that it can be processed in order for noise study. Each file will have unique name that
indicates the film type, material, thickness substrate temperature of the film and other physical parameters applied for the noise study.

The recorded noise is analysed using MATLAB program which reads the .WAV files and applies various DSP function like FFT and filtering to give out graph of the power spectral density of the film verses frequency. Special care has been taken to display graphs with different colours and symbols to identify and compare the graphs of different films. The detailed program listing is presented in chapter 4.

5.6 RESULTS AND DISCUSSIONS IN METALLIC THIN FILMS

Typical noise records are shown in following figures (Fig 5.1 and 5.2) for tellurium at three different observations. These plots represent the noise recorded for one individual device. On observation, the noise recordings look alike on first perusal. Nothing seems to be differentiated between any two plots except the noise magnitudes are different.

However the noise patterns similar to shown in Fig 5.1 and Fig 5.2 are the essential inputs to all programs being run under MATLAB environment. Each device under selected biased condition has its own record in the form of digital data file (which is not provided). These when plotted directly look alike, the differences in magnitudes can be noticed but quantitative measurements can’t be made. The spectral power density records are obtained using the digital data records as inputs to the MATLAB programs discussed in Chapter 4. These FFT records have the unique signatures of noise produced by the device under test, abbreviated as DUT.

The raw noise records for Tellurium film of 6620A° at different observations are shown in Fig 5.1 and Fig 5.2. As already pointed out the raw noise records do not convey any meaning. The observation is of prime significance, containing crucial information regarding the electrical behaviour associated with DUT if analysed using MATLAB programs. Its simple graphical presentation is of no usage except the noise magnitudes can be compared.

Fig 5.3 record is averaged power spectral density record. The most simple way of translating the noise data into spectral power density form is known as FFT transform of the noise input. It is an averaged FFT record obtained from the noise records of Fig 5.1 and 5.2. Similarly, all FFT records (Fig 5.4 to 5.50) plotted in this chapter represent averaged FFT records of three or more noise observations measured on a selected device under the specified
Fig. 5.1 Noise amplitude of 66.20 Å Tellurium film on Mica at 2.207 Å Cm² for different temperatures.
Fig 5.2 FFT amplitude of 6620 Å Tellurium film on Mica at 2.207 Å cm⁻² for different temperatures.
Fig 5.3 1/f noise of 6620 Å* Tellurium film on Mica at 2.207 Acm² for different temperatures
Fig 5.4 - $1/f$ noise of 400Å Aluminium film at different current densities A cm$^{-2}$.

Fig 5.5 - $1/f$ noise of 500Å Aluminium film at different current densities A cm$^{-2}$.
Fig 5.6 - 1/f noise of 600Å Aluminium film at different current densities A cm$^{-2}$

Fig 5.7 - 1/f noise of 830Å Aluminium film at different current densities A cm$^{-2}$
Fig 5.8 1/f noise of Aluminium films of different thickness when constant current of 7.5 mA is passed through them under same experimental environment.

Fig 5.9 1/f noise of Aluminium films of different thickness when constant current of 10 mA is passed through them under same experimental environment.
Fig 5.10 1/f noise of Aluminium films of different thickness when constant current of 12 mA is passed through them under same experimental environment.

Fig 5.11 1/f noise of Aluminium films of different thickness when constant current of 15 mA is passed through them under same experimental environment.
Fig 5.12 1/f noise of 400Å Silver film at different current densities A cm$^{-2}$

Fig 5.13 1/f noise of 660Å Silver film at different current densities A cm$^{-2}$
Fig 5.14 1/f noise of 880Å Silver film at different current densities A cm\(^{-2}\)

Fig 5.15 1/f noise of 1100Å Silver film at different current densities A cm\(^{-2}\)
Fig 5.16 - $1/f$ noise of Silver films of different thickness when constant current of 10 mA is passed through them under same experimental environment.

Fig 5.17 - $1/f$ noise of Silver films of different thickness when constant current of 50 mA is passed through them under same experimental environment.
Fig 5.18 - 1/f noise of 1100Å Gold film at different current densities (A/Cm²)

Fig 5.19 - 1/f noise of 880Å Gold film at different current densities (A/Cm²)
Fig 5.20 - 1/f noise of 440Å Gold film at different current densities (A/Cm²)
Fig 5.21. 1/f noise of Aluminium, Gold and Silver films of 400Å thickness when current density is maintained at 4545.5 Acm⁻².

Fig 5.22. 1/f noise of Aluminium, Gold and Silver films of 400Å thickness when current density is maintained at 1136.5 Acm⁻².
Fig 5.23 - 1/f noise of 10000Å Cu$_2$Se film at different current densities A cm$^{-2}$

Fig 5.24 - 1/f noise of 6000Å Cu$_2$Se film at different current densities A cm$^{-2}$
Fig 5.25 - $1/f$ noise of 46000 $\AA$ Cu$_2$Se thin film on glass substrate at different temperatures.

Fig 5.26 Variation of dynamic resistance of Cu$_2$Se 46000 $\AA$ film on glass substrate at different temperatures.
Fig 5.27 - 1/f noise of 85000 Å Cu$_2$Se thin film on glass substrate at different temperatures.

Fig 5.28 Variation of dynamic resistance of Cu$_2$Se 85000 Å film on glass substrate at different temperatures.
Fig 5.29 1/f noise of 104000 Å Cu$_2$Se thin film on glass substrate at different temperatures.
Fig 5.30 1/f noise of 46000 Å Cu$_2$Se thin film on mica substrate at different temperatures.

Fig 5.31 1/f noise of 61000 Å Cu$_2$Se thin film on mica substrate at different temperatures.
Fig 5.32 1/f noise of 85000 Å Cu₂Se thin film on mica substrate at different temperatures.

Fig 5.33 1/f noise of 104000 Å Cu₂Se thin film on mica substrate at different temperatures.
Fig 5.34 - $1/f$ noise of 800Å CdSe film on glass substrate at different current densities $A \text{ cm}^{-2}$

Fig 5.34 - $1/f$ noise of 10000Å CdSe film on glass substrate at different current densities $A \text{ cm}^{-2}$
Fig 5.36 1/f noise of 10000 Å CdSe thin film on glass substrate at different temperatures.

Fig 5.37 - Variation of dynamic resistance of 10000 Å CdSe thin film on glass substrate at different temperatures.
Fig 5.38 - 1/f noise of 6000 Å CdSe thin film on glass substrate at different temperatures

Fig 5.39 - Variation of dynamic resistance of 8000 Å CdSe thin film on glass substrate at different temperatures
Fig 5.40 1/f noise of 10180Å Tellurium film on glass substrate at different current densities A cm^{-2}

Fig 5.41 1/f noise of 66200Å Tellurium film on Mica substrate at different current densities A cm^{-2}
Fig 5.42 - 1/f noise of 10180 Å Tellurium thin film on glass substrate at different temperatures.

Fig 5.43 - 1/f noise of 6620 Å Tellurium thin film on glass substrate at different temperatures.
Fig 5.44 - 1/f noise of 4590 Å Tellurium thin film on mica substrate at different temperatures.

Fig 5.45 - Variation of dynamic resistance of 4590 Å Tellurium film on mica at different temperatures.
Fig 5.46 - $1/f$ noise of 6620 Å Tellurium thin film on mica substrate at different temperatures.

Fig 5.47 - Variation of dynamic resistance of 6620 Å Tellurium film on mica at different temperatures.
Fig 5.48 1/f Noise of Cu$_2$Se 10000 A films on glass grown by maintaining substrate at 410K, 360K and 310K at current density 3.161 A/Cm$^2$.

Fig 5.49 1/f Noise of Cu$_2$Se 10000 A films on glass grown by maintaining substrate at 410K, 360K and 310K at current density 4.214 A/Cm$^2$. 
Fig 5.50 1/f Noise of Cu$_2$Se 10000 Å films on glass grown by maintaining substrate at 410K, 360K and 310K at current density 6.321 A/cm$^2$
conditions. All graphs are plotted in the standard format of \( \log f \) verses \( \log (\text{spectral power density}) \), after passing the data through the elliptical filter. The elliptical filters are found to be quite suitable for measurements that are recorded randomly. Notch filters were also used in the software to eliminate the stray ac interference. These graphs convey better information when they are compared for different devices or under different conditions for the same DUT. Plotting them on the same graphical presentation compares two or more plots. This is equivalent to superimposing multiple graphs presented on similar scales. To visualize the difference we plotted different plots using different colours. A legend to each graph is added for easy explanation. In the present work we have studied \( 1/f \) noise dependence on different conditions. Films of different thickness are used for each material. Films are formed at different substrate temperature for one of the specimen. Temperature of each specimen of semiconductor thin films is varied and \( 1/f \) noise determined. For one of the semiconductors films are formed on glass and mica for \( 1/f \) noise studies. We have carefully compared the \( 1/f \) noise plots to achieve the objectivity of \( 1/f \) noise studies.

5.6.1. \( 1/f \) NOISE IN THIN FILMS OF METALLIC ALUMINIUM

As pointed out already, spec pure metallic samples of better than 99.99% purity are used in the present work (unless otherwise specified). Thin films of aluminium were grown under the conditions stipulated in Table 5.2. The stable films of aluminium of thickness 400 Å, 500 Å, 600 Å and 830 Å are studied in the present work. Two sets of each thickness are grown and kept in desiccators, since clean aluminium surface, exposed to the environment, gets oxidised. Spectral density in the form of averaged magnitude of FFT is plotted as a function of frequency on a log-log plot. Fig 5.4 is a plot for 400 Å thicknesses for five current densities as presented in the figure. For strict \( 1/f \) noise compliance, a linear dependence of frequency versus FFT is expected. That is, FFT decreases with frequency, proportional to \( f^\gamma \), where \( \gamma = -1 \) for a strict \( 1/f \) noise compliance. The ideal behaviour known as \( 1/f \) behaviour is sparingly observed in \( 1/f \) noise studies. We have included the \( 1/f \) line for every FFT plot, and also evaluated the value of \( \gamma \).
Table 5.3 – \( \gamma \) values derived from Fig 5.4 for various frequency regions in 400 A° films

<table>
<thead>
<tr>
<th>Current Density</th>
<th>Below 1 kHz Frequency</th>
<th>Between 1 kHz and 10 kHz</th>
<th>Averaged for the full range</th>
</tr>
</thead>
<tbody>
<tr>
<td>3950 A cm(^2)</td>
<td>-0.549</td>
<td>-0.431</td>
<td>-0.500</td>
</tr>
<tr>
<td>3160 A cm(^2)</td>
<td>-0.570</td>
<td>-0.460</td>
<td>-0.516</td>
</tr>
<tr>
<td>2633 A cm(^2)</td>
<td>-0.568</td>
<td>-0.464</td>
<td>-0.516</td>
</tr>
<tr>
<td>2257 A cm(^2)</td>
<td>-0.627</td>
<td>-0.491</td>
<td>-0.567</td>
</tr>
<tr>
<td>1975 A cm(^2)</td>
<td>-0.674</td>
<td>-0.539</td>
<td>-0.617</td>
</tr>
</tbody>
</table>

For 400 A° thickness we observed that \( \gamma = -0.617 \) for a current density of 1975 A cm\(^2\), while \( \gamma = -0.500 \) for current density of 3950 A cm\(^2\). As the current density is increased the power \( \gamma \) also tends to increase. It would be quite interesting to check the linearity of \( \gamma \) as a function of current density. The observed values of \( -\gamma \) are 0.5, 0.516, 0.516, 0.567 and 0.617 for aluminium films with current densities (A cm\(^2\)) 3950, 3160, 2633, 2257 and 1975 respectively. These values of \( -\gamma \) are plotted as a function of current density in Fig 5.4a. The \( -\gamma \) values are appearing to approach the theoretical value of unity for lower currents as visualised in literature [8]. About ± 2% errors are expected in the measured values of \( \gamma \). It has not been possible to study the films of thickness below 400° since the measurements on these films were quite unreliable due to very large fluctuations. It has been observed that literature values of \( -\gamma \) are higher than the present values [8].
Fig 5.4a - Current density (x-axis) versus noise factor (-\gamma) in the range of study for Aluminium films of 400 Å thickness.

It can be observed that the slopes are not uniform throughout the frequency region of study. The slopes are slightly higher than the mean slopes in the low frequency region, below 1 kHz. The slopes are lower than the mean value in the upper region 1 kHz and 10 kHz. The slopes are tabulated in Table 5.3 for aluminium of 400 Å thicknesses.
l/f noise in aluminium thin films of 500 Å thicknesses is presented in Fig 5.5. The extreme values are $\gamma = -0.67$ for the current density of 1580 A cm$^{-2}$ while $\gamma = -0.56$ for current density of 3650 A cm$^{-2}$. Fig 5.5 is almost similar to Fig 5.4 except that the current densities of two studies are different. The mean $\gamma$ values are determined in a similar fashion and tabulated for 500 Å thicknesses of aluminium films.

Table 5.4 – $\gamma$ Values Derived from Fig 5.5 for the lower and upper frequency regions for Aluminium films of 500 Å

<table>
<thead>
<tr>
<th>Current Density</th>
<th>Below 1kHz Frequency</th>
<th>Between 1kHz and 10 kHz</th>
<th>Averaged for the full range</th>
</tr>
</thead>
<tbody>
<tr>
<td>3650 A cm$^{-2}$</td>
<td>-0.616</td>
<td>-0.512</td>
<td>-0.560</td>
</tr>
<tr>
<td>2528 A cm$^{-2}$</td>
<td>-0.625</td>
<td>-0.502</td>
<td>-0.570</td>
</tr>
<tr>
<td>2107 A cm$^{-2}$</td>
<td>-0.642</td>
<td>-0.492</td>
<td>-0.580</td>
</tr>
<tr>
<td>1806 A cm$^{-2}$</td>
<td>-0.670</td>
<td>-0.537</td>
<td>-0.620</td>
</tr>
<tr>
<td>1580 A cm$^{-2}$</td>
<td>-0.726</td>
<td>-0.599</td>
<td>-0.670</td>
</tr>
</tbody>
</table>

Fig 5.6 is the l/f noise plots of aluminium film of thickness 600 Å. The values of from the study yields $\gamma = -0.747$ for the current density of 1316 A cm$^{-2}$ while $\gamma = -0.600$ for current density of 2633 A cm$^{-2}$. The l/f behaviour of 600 Å thicknesses, Fig 5.6, is almost similar to the lower thickness behaviour of Fig 5.4 and Fig 5.5. A table of variation of $\gamma$ is not included for Fig 5.6.

Fig 5.5a – Current density (x-axis) versus noise factor (-$\gamma$) in the range of study for Aluminium films of 500 Å thickness.
Fig 5.6a – Current density (x-axis) versus noise factor (\(\gamma\)) in the range of study for Aluminium films of 600 Å thickness.

The 1/f study of 830 Å thickness Fig 5.7 yields \(\gamma = -0.832\) for a current density of 952 A cm\(^{-2}\) while \(\gamma = -0.738\) for current density of 1904 A cm\(^{-2}\). The 1/f plots appear to be quite close to each other for various current densities. The magnitude of difference in slope per unit current density change is lesser compared to Fig 5.4 or Fig 5.6 or Fig 5.6. It was not possible to
increase the current density in this specimen due to instability at higher currents. It would be quite interesting to study the 1/f noise of aluminium foils to ascertain this behaviour. We could unable to procure aluminium foils of about 4000 to 5000 Å thickness during the period of this study.

The nature of variation of $\gamma$ with current density is almost similar in all the figures Fig 5.4a, Fig 5.5a and Fig 5.6a. In Fig 5.7a the rate of increase in noise factor appears to be smaller. However the trend of increase with increasing current is evident. Two regions can be clearly demarcated in all the figures. Region (1), the low current density region, which tend to lowest value of $\gamma = -1$ as the current is increased; and Region (2) the high current region where the $\gamma$ value increases as the current is increased and settles to a $\gamma \approx -0.5$. Several workers reported an increase in $\gamma$ value on increase of the current density.

It would be interesting to study the 1/f noise in aluminium films of different thickness maintained at constant current or current density. Films of 400 Å, 500 Å, 600 Å and 830 Å thickness are subject to flow of constant current of 7.5 mA and corresponding 1/f response is plotted in Fig 5.8. The variation of slope as a function of thickness at 7.5 mA is plotted in Fig 5.8a. Since only four films of different thickness have been grown, the observations derived appear to be only qualitative. However, similar results are observed for the currents of 10 mA, 12 mA and 15 mA, when the films of different thickness are employed.

Fig 5.8a – Thickness Å (x-axis) versus noise factor (-γ) at 7.5 mA current.
In Fig 5.8a the value of \( y \) appears to decrease with increasing thickness and seem to tend to \(-1\) at higher thickness. The \( y \) value also appears to settle down to \(-0.5\) for lower thickness. As already explained these remarks made with due reservation, are to be confirmed by investigating a large number of thin film samples. In the present study, due to limited resources, a large number of films could not be investigated.

Table 5.5 – Average Slopes of various 1/f graphs at the Specific Current Density in Aluminium

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Current Density</th>
<th>Average Slope ( y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.4</td>
<td>400 A° Aluminum film at different current densities.</td>
<td>Magenta</td>
<td>3950 A cm(^{-2})</td>
<td>-0.500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>3160 A cm(^{-2})</td>
<td>-0.516</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>2633 A cm(^{-2})</td>
<td>-0.516</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>2257 A cm(^{-2})</td>
<td>-0.567</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>1975 A cm(^{-2})</td>
<td>-0.617</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.5</td>
<td>500 A° Aluminum film at different current densities.</td>
<td>Magenta</td>
<td>3650 A cm(^{-2})</td>
<td>-0.560</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>2528 A cm(^{-2})</td>
<td>-0.570</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>2107 A cm(^{-2})</td>
<td>-0.580</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>1806 A cm(^{-2})</td>
<td>-0.620</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>1580 A cm(^{-2})</td>
<td>-0.670</td>
</tr>
<tr>
<td>3</td>
<td>Fig 5.6</td>
<td>600 A° Aluminum film at different current densities.</td>
<td>Magenta</td>
<td>2633 A cm(^{-2})</td>
<td>-0.600</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>2107 A cm(^{-2})</td>
<td>-0.610</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>1755 A cm(^{-2})</td>
<td>-0.650</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>1505 A cm(^{-2})</td>
<td>-0.700</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>1316 A cm(^{-2})</td>
<td>-0.747</td>
</tr>
<tr>
<td>4</td>
<td>Fig 5.7</td>
<td>830 A° Aluminum film at different current densities.</td>
<td>Magenta</td>
<td>1904 A cm(^{-2})</td>
<td>-0.738</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>1523 A cm(^{-2})</td>
<td>-0.761</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>1269 A cm(^{-2})</td>
<td>-0.771</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>1088 A cm(^{-2})</td>
<td>-0.805</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>952 A cm(^{-2})</td>
<td>-0.832</td>
</tr>
</tbody>
</table>

In a similar manner 1/f plots of the four samples are studied at each constant current (of 10 mA, 12 mA and 15 mA) in Figs 5.9, 5.10 and 5.11 respectively. When \(-\gamma\) values are evaluated and plotted, the behaviour is almost similar to that presented in Fig 5.8a. Since no new observation is made, plots similar to Fig 5.8a are not presented corresponding to 10 mA, 12 mA and 15 mA.

We preferred to plot Figs 5.8 to 5.11 at constant currents instead of current densities. However Table 5.5 provides the current densities corresponding to the dc currents in mA.
Several workers discussed on the basis of current flowing through the films instead of current densities [8]. Table 5.6 presents values of current densities corresponding to the specified currents of column 1.

<table>
<thead>
<tr>
<th>Constant Currents Passed in Films</th>
<th>Current Density corresponding to Column 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>400 Å° thickness</td>
</tr>
<tr>
<td>7.5 mA</td>
<td>1875 A cm²</td>
</tr>
<tr>
<td>10 mA</td>
<td>1500 A cm²</td>
</tr>
<tr>
<td>12 mA</td>
<td>1250 A cm²</td>
</tr>
<tr>
<td>15 mA</td>
<td>903 A cm²</td>
</tr>
</tbody>
</table>

The average slopes of $1/f$ plots at constant current passed in films of different thickness are presented in Table 5.7. It has been already observed that, for a given film, the $\gamma$ values decrease and appear to tend to minus one for diminishing currents or current densities. Similarly $\gamma$ values settle to a maximum of $\gamma \approx -0.5$ for thinner films and exhibit $1/f$ noise behaviour ($\gamma = -1$) only for films of about 1000 Å° thickness for aluminium.

Table 5.7 – Average Slopes of various $1/f$ graphs different Currents in Aluminium films

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Thickness</th>
<th>Average Slope $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.8</td>
<td>7.5 ma Through Aluminum films of different thickness</td>
<td>Magenta</td>
<td>400 Å°</td>
<td>-0.608</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>500 Å°</td>
<td>-0.668</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>600 Å°</td>
<td>-0.744</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>830 Å°</td>
<td>-0.827</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.9</td>
<td>10 ma Through Aluminum films of different thickness</td>
<td>Magenta</td>
<td>400 Å°</td>
<td>-0.526</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>500 Å°</td>
<td>-0.574</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>600 Å°</td>
<td>-0.655</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>830 Å°</td>
<td>-0.778</td>
</tr>
<tr>
<td>3</td>
<td>Fig 5.10</td>
<td>12 ma Through Aluminum films of different thickness</td>
<td>Magenta</td>
<td>400 Å°</td>
<td>-0.502</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>500 Å°</td>
<td>-0.552</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>600 Å°</td>
<td>-0.612</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>830 Å°</td>
<td>-0.742</td>
</tr>
<tr>
<td>4</td>
<td>Fig 5.11</td>
<td>15 ma Through Aluminum films of different thickness</td>
<td>Magenta</td>
<td>400 Å°</td>
<td>-0.500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>500 Å°</td>
<td>-0.570</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>600 Å°</td>
<td>-0.600</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>830 Å°</td>
<td>-0.741</td>
</tr>
</tbody>
</table>
5.6.2. 1/f NOISE IN THIN FILMS OF SILVER

Spec pure silver samples of 99.995% purity are used in the present work. Thin films of silver were grown under the conditions stipulated in Table 5.2. The stable films of silver of thickness 400 Å, 660 Å, 880 Å and 1100 Å are studied in the present work. Films are grown and kept in desiccators since clean silver surface on exposed to atmosphere, become dull due to chlorination. Power spectral density, in the form of averaged magnitude of FFT, is plotted as a function of frequency.

Fig 5.12 is a plot for 400 Å thicknesses for three current densities. The theoretical estimates predict $\gamma = -1$, while the observed values of $-\gamma$ are 0.535, 0.532 and 0.540 for silver films of 400 Å thickness, at current densities (A/cm²) 3192, 2612 and 2210 respectively. Accounting the estimated error of ± 2%, the observed values of $\gamma$ are constant for the three current densities. On increasing the current density, the power $\gamma$ tends to increase for devices [67,68] and thin films [8]. However for silver no variation is observed within the small range of current densities studied in this work. It was not possible to extend the range of current densities due to instability and current fluctuations that result at these large currents. It is observed that literature values of $-\gamma$ are much higher than the present values [8].

1/f noise in silver thin films of 660 Å thicknesses is presented in Fig 5.13. Almost constant value of $\gamma = -0.531$ is observed for the three current densities studied in Fig 5.13. Fig 5.13 is almost similar to Fig 5.12 except that the current densities of study are different.

Fig 5.14 and Fig 5.15 are the 1/f noise plots of silver films of thickness 880 Å and 1100 Å respectively. The study yields $\gamma$ values of -0.507 and -0.564 respectively for thickness 880 and 1100 Å respectively. The behaviour in Fig 5.14 and Fig 5.15 is similar to the case of Figs 5.12 or 5.13. For the four silver films studied in this work the $-\gamma$ remains in the range 0.5 to .57. The average slopes evaluated for Figs 5.12 to 5.15 are tabulated in Table 5.8.
Table 5.8 - Average Slopes of various 1/f graphs at the Specific Current Density in Silver films

<table>
<thead>
<tr>
<th>SL No</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Current Density</th>
<th>Average Slope $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.12</td>
<td>400 A° Silver film at different current densities</td>
<td>Magenta</td>
<td>3192 A cm$^{-2}$</td>
<td>-0.535</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>2612 A cm$^{-2}$</td>
<td>-0.532</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>2210 A cm$^{-2}$</td>
<td>-0.540</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.13</td>
<td>660 A° Silver film at different current densities</td>
<td>Magenta</td>
<td>2128 A cm$^{-2}$</td>
<td>-0.535</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>1741 A cm$^{-2}$</td>
<td>-0.530</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>1473 A cm$^{-2}$</td>
<td>-0.528</td>
</tr>
<tr>
<td>3</td>
<td>Fig 5.14</td>
<td>880 A° Silver film at different current densities</td>
<td>Magenta</td>
<td>1596 A cm$^{-2}$</td>
<td>-0.504</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>1306 A cm$^{-2}$</td>
<td>-0.508</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>1105 A cm$^{-2}$</td>
<td>-0.510</td>
</tr>
<tr>
<td>4</td>
<td>Fig 5.15</td>
<td>1100 A° Silver film at different current densities</td>
<td>Magenta</td>
<td>1277 A cm$^{-2}$</td>
<td>-0.560</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>1044 A cm$^{-2}$</td>
<td>-0.564</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>884 A cm$^{-2}$</td>
<td>-0.568</td>
</tr>
</tbody>
</table>

The observations made in Figs 5.12, 5.13, 5.14 and 5.15 are clearly reflected in Fig 5.16 when the noise patterns are plotted for the four thickness 400, 660, 880 and 1100 A° at constant current of 10 mA. The magnitude of noise is increasing with decreasing thickness, but $-\gamma$ assumes values of 0.527, 0.492, 0.510 and 0.530 (when entire frequency range is considered) for 400, 660, 880 and 1100 A° thickness respectively. A visual examination of Fig 5.16 reveals that the slopes of all the three lower thickness remain constant with $-\gamma = 0.518$ (in the frequency range 100 Hz to 10 kHz), for the remaining thickness the slope $-\gamma = 0.53$. These values can be treated as constant when the combined errors of 2% are accounted for each measurement.

In a similar fashion, at 50 mA current in Fig 5.17, the magnitude of noise is increasing with decreasing thickness, but $-\gamma$ assumes values of 0.504, 0.510, 0.497 and 0.523, when entire frequency range is considered, for 400, 660, 880 and 1100 A° thickness respectively. When the combined experimental errors are accounted these values can be treated as constant.

However, the magnitude of noise is clearly increasing with decreasing thickness of the films both in Figs 5.16 and Fig 5.17, in accordance with the observations made in literature [8]. The noise factor is around the −0.5 magnitude for the two extreme currents. Wider current ranges could not be studied due to the instability introduced on passing continuous currents.
may be possible to study 1/f noise using pulsed currents instead of continuous dc. We did not attempt to extend our studies using pulsed unidirectional currents.

Table 5.9 – Average Slopes of various 1/f graphs at different Currents in Silver films

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Thickness</th>
<th>Average Slope $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.16</td>
<td>10 ma Through Silver films of different thickness</td>
<td>Magenta</td>
<td>1100 Å°</td>
<td>-0.530</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>880 Å°</td>
<td>-0.510</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>660 Å°</td>
<td>-0.492</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>400 Å°</td>
<td>-0.527</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.17</td>
<td>50 ma Through Silver films of different thickness</td>
<td>Magenta</td>
<td>1100 Å°</td>
<td>-0.523</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>880 Å°</td>
<td>-0.497</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>660 Å°</td>
<td>-0.510</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>400 Å°</td>
<td>-0.504</td>
</tr>
</tbody>
</table>

5.6.3 1/f NOISE IN THIN FILMS OF GOLD

Spec pure gold samples of 99.995% purity are used in the present work. Thin films of gold were grown under the conditions stipulated in Table 5.2. The stable films of gold of thickness 400 Å°, 880 Å° and 1100 Å° are studied in the present work. Films are grown and kept in desiccators to preserve the surface from atmospheric interactions.

Power spectral density, in the form of averaged magnitude of FFT, is plotted as a function of frequency. Fig 5.18 is a plot for 1100 Å° thickness for three current densities. The theoretical estimates predict $\gamma = -1$, while the observed values of $-\gamma$ are 0.661, 0.650 and 0.670 for gold films of 1100 Å° thickness, at current densities 2633, 3160 and 3950 Å cm$^{-2}$ respectively. Accounting the estimated error of ± 2%, the observed values are constant for the three current densities. On decreasing the current density, the power $\gamma$ tends to increase for devices [67,68] and thin films [8]. However for silver and gold films no variation is observed within the small range of current densities studied in this work. It was not possible to extend the range of current densities due to instability and current fluctuations that result at these large currents. It is observed that literature values of $-\gamma$ are much higher than the present values [8].
Fig 5.19 is a plot for 880 Å thickness for three current densities. The ideal $\gamma = -1$ is presented in the graph. The observed values of $-\gamma$ are 0.542, 0.541 and 0.563 for gold films of 880 Å thickness, at current densities 2633, 3160 and 3950 Å cm$^{-2}$ respectively. On accounting the estimated error of ± 2%, the observed values are very close to constant value 0.549.

Fig 5.20 is the 1/f noise plots of gold films of thickness 400 Å. The study yields $\gamma$ values of -0.542, -0.543 and -0.550 respectively for the current densities 2633, 3160 and 3950 Å cm$^{-2}$. On accounting the estimated error of ± 2%, the observed values are constant (0.545).

Table 5.10 – Average Slopes of 1/f graphs at the Various Current Densities in Gold films

<table>
<thead>
<tr>
<th>SL. No</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Current Density</th>
<th>Average Slope $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.18</td>
<td>1100 Å Gold film at different current densities</td>
<td>Magenta</td>
<td>3950 Å cm$^{-2}$</td>
<td>-0.670</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>3160 Å cm$^{-2}$</td>
<td>-0.650</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>2633 Å cm$^{-2}$</td>
<td>-0.661</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.19</td>
<td>880 Å Gold film at different current densities</td>
<td>Magenta</td>
<td>3950 Å cm$^{-2}$</td>
<td>-0.563</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>3160 Å cm$^{-2}$</td>
<td>-0.541</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Yellow</td>
<td>2633 Å cm$^{-2}$</td>
<td>-0.542</td>
</tr>
<tr>
<td>3</td>
<td>Fig 5.20</td>
<td>400 Å Gold film at different current densities</td>
<td>Magenta</td>
<td>3950 Å cm$^{-2}$</td>
<td>-0.550</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>3160 Å cm$^{-2}$</td>
<td>-0.543</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Yellow</td>
<td>2633 Å cm$^{-2}$</td>
<td>-0.542</td>
</tr>
</tbody>
</table>

The values remain almost constant within the range of current densities studied in this work for various thicknesses. The behaviour is similar to the case of Figs 5.12 or 5.13. For the four gold films studied in this work the $-\gamma = 0.5$ and is observed to remain constant even if current density is varied from 900 to 3200 Å cm$^{-2}$.

When 1/f noise results in gold (Figs 5.18, 5.19 and 5.20) are compared with 1/f noise results in silver (Figs 5.12, 5.13, 5.14 and 5.15), it is very clear that thin films of gold and silver behave in a similar fashion.
5.6.4 COMPARISON OF 1/f NOISE IN THIN FILMS OF ALUMINIUM, SILVER AND GOLD

In view of the similarities exhibited by silver and gold thin films (in 1/f noise studies), it would be quite interesting to compare the 1/f noise produced in thin films of aluminium, silver and gold under identical condition. The thin films of gold, silver and aluminium of 400 Å are investigated in this study. The films are subject to two extreme current densities 4545.5 A cm⁻² and 1136.5 A cm⁻². Fig 5.21 is a 1/f noise study for gold, silver and aluminium at a constant current of 4545.5 A cm⁻². The magnitudes of 1/f noise of gold and silver films are almost same while the magnitude of aluminium film is much higher (about 5 to 6 times larger than those of the gold films in 100 Hz to 10 kHz frequency range). Moreover the 1/f slope of aluminium film at the current density of 4545.5 A cm⁻² is quite non-linear and exhibits different γ values (since γ, the slope, is frequency dependent). γ of aluminium film is found to vary between −0.6 to −0.87 as the frequency is increased from 100 Hz to 10 kHz while that of gold and silver are constant (about −0.849 mean value).

In a similar fashion the 1/f plots of gold, silver and aluminium of 400 Å thicknesses are investigated by adjusting the current density as 1136.5 A cm⁻² in Fig 5.22. The slopes of gold and silver are almost same. The magnitudes of 1/f noise of gold and silver films are almost same while the magnitude of aluminium film is higher (about 2 to 3 times larger than those of the gold films in 100 Hz to 10 kHz frequency range). The 1/f slope of aluminium film at the current density of 1136.5 A cm⁻² is non-linear and exhibits different γ values (since γ, the slope, is frequency dependent). γ of aluminium film is found to vary between −0.55 to −0.82 as the frequency is increased from 100 Hz to 10 kHz while that of gold and silver are constant with a value of about −0.817.

Table 5.11 - Average Slopes of 1/f graphs of Gold, Silver and Aluminium of 400 Å Thickness at Two Current Densities (Derived from Figs 5.21 and 5.22)

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Material of the Thin Film</th>
<th>Average Slope γ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.21</td>
<td>Al, Au and Ag films at 4545.5 A cm⁻² current density</td>
<td>Magenta</td>
<td>Aluminum</td>
<td>−0.766</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>Gold</td>
<td>−0.838</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>Silver</td>
<td>−0.860</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.22</td>
<td>Al, Au and Ag films at 1136.5 A cm⁻² current density</td>
<td>Magenta</td>
<td>Aluminum</td>
<td>−0.682</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>Gold</td>
<td>−0.818</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>Silver</td>
<td>−0.817</td>
</tr>
</tbody>
</table>
5.7 RESULTS AND DISCUSSIONS IN SEMICONDUCTORS

5.7.1 COPPER SELENIDE THIN FILMS

Thin films of copper selenide of thickness 10000, 46000, 61000 & 85000 Å are prepared on glass substrate and mica substrate at 10 Å/s deposition rates maintained at 2 x 10⁻⁵ mbar pressure. Separate films are grown at three different substrate temperatures (310 K, 360 K and 410 K).

The 1/f noise studies on copper selenide of 10000 Å maintained at room temperature (see Fig 5.48) at a current density is 3.161 A/cm² reveal that the three specimens grown at 310 K, 360 K and 410 K yield γ values -0.853, -0.837 and -0.848 respectively. The absolute magnitudes of the noise differ slightly but there is no appreciable difference in noise factor γ. Similarly the γ estimated from Fig 5.49 for copper selenide of 10000 Å thicknesses with a current density 4.214 A/cm² yield -0.585, -0.565 and -0.573 respectively. Similarly Fig 5.50 1/f noise plot for the same film maintained at room temperature and 6.321 A/cm² yields γ values of -0.687, -0.647 and -0.653. For a given current density the noise amplitudes slightly differ but the γ remains constant. Since the γ values are insensitive to the substrate temperatures, we measured the other parameters using specimens grown at 310 K.

However, the films of same thickness grown on glass behave quite differently from those grown on mica. These observations made us to present the noise results of different substrates in the two following sections.

5.7.1a. 1/f NOISE IN THIN FILMS OF COPPER SELENIDE ON GLASS SUBSTRATE GROWN AT 310°C

Extra pure specimens of copper and selenium samples of 99.999% purity are used for the thin film deposition using flash evaporation technique. Stoichiometric compositions are maintained right from powdering to thin film deposition on glass and mica. The conductivity and activation energy at 410 K in the deposited thin films are of the order of 100 to 1300 mho m⁻¹ and 1.7 to 0.5 eV respectively. The deposited films are tested in the laboratory and the samples that satisfy the specified stoichiometric composition limit are only passed.
Normally pure copper selenide results into a degenerate p-type semi-conductor with a typical carrier concentration of \(1.3 \times 10^{13} \text{ m}^{-3}\) at room temperature \([104]\) for 10000 Å film. We have not attempted to measure the concentration in individual films of various thickness. As already mentioned copper selenide films of thickness 10000, 46000, 61000 & 85000 Å are deposited, using flash evaporation on glass substrate, at 10 Ås\(^{-1}\) deposition rates, maintained at 2 \(\times\) 10\(^{-5}\) mbar pressure. Films are deposited at three different substrate temperatures 310 K or 360 K or 410 K. Since the films of same thickness grown at different substrate temperatures do not show any difference in the 1/f noise property, we selected the films grown at 310 K for all the studies. These films are being simultaneously used for the study of other physical properties and the results are being published \([69, 103\text{ and } 104]\).

Power spectral density, in the form of averaged magnitude of FFT, is plotted as a function of frequency for thinnest film of copper selenide (10000 Å thickness) for five current densities. The theoretical estimate of \(\gamma = -1\) presented as solid black line. The observed values of \(-\gamma\) at current densities 0.843, 1.054, 1.405, 2.107 and 4.214 Å cm\(^{-2}\) are 0.722, 0.681, 0.690, 0.641 and 0.590 respectively. On decreasing the current density, the power \(\gamma\) tends to decrease for this thin film of copper selenide as shown in Fig 5.23a. However for the films of aluminium the \(\gamma\) values are found increase with decreasing current.

Fig 5.23a - Current density Åcm\(^{-2}\) (x-axis) versus noise factor (-\(\gamma\)) in the range of study for Copper Selenide films of 10000 Å thickness on glass at 310 K. The change in \(\gamma\) with increasing current is positive in Copper Selenide.
It was not possible to extend the range of current densities due to instability and current fluctuations that result at these large currents.

![Graph showing current density vs noise factor](image)

**Fig 5.24a** - Current density $\text{Acm}^{-2}$ (x-axis) versus noise factor (-$\gamma$) in the range of study for Copper Selenide films of 46000 Å thickness on glass at 310K. The change in $\gamma$ with increasing current is positive in Copper Selenide.

FFT is similarly plotted as a function of frequency in Fig 5.24 for the 46000 Å thickness films of copper selenide at five current densities. The theoretical estimate of $\gamma$ is -1 and the observed values of -$\gamma$ at current densities 0.950, 1.141, 1.630, 3.803 and 5.705 A cm$^{-2}$ are 0.857, 0.847, 0.825, 0.788 and 0.786 respectively. On decreasing the current density, the power $\gamma$ tends to decrease for this thin film of copper selenide as shown in Fig 5.24a. By comparing Fig 5.23 and Fig 5.24, it is noticed that $\gamma$ is decreasing as the thickness is increased. The $\gamma$ values are also decreasing to a limiting value of -1 as the current is decreasing in copper selenide thin films. Average slopes evaluated from Fig 5.23 and Fig 5.24 is tabulated in Table 5.12, the average $\gamma$ value appear to tend to -1 for lower currents and also for higher thickness of films.
Table 5.12 – Average Slopes of 1/f graphs in Copper Selenide Films of Thickness 10000 Å and 46000 Å at Various Current Densities

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Current Density</th>
<th>Average Slope γ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.23</td>
<td>10000 Å Cu₂Se at different current densities</td>
<td>Magenta</td>
<td>4.214 Å cm⁻²</td>
<td>-0.590</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>2.107 Å cm⁻²</td>
<td>-0.641</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>1.405 Å cm⁻²</td>
<td>-0.690</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>1.054 Å cm⁻²</td>
<td>-0.681</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>0.843 Å cm⁻²</td>
<td>-0.722</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.24</td>
<td>46000 Å Cu₂Se at different current densities</td>
<td>Magenta</td>
<td>5.705 Å cm⁻²</td>
<td>-0.786</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>3.803 Å cm⁻²</td>
<td>-0.788</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>1.630 Å cm⁻²</td>
<td>-0.825</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>1.141 Å cm⁻²</td>
<td>-0.847</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>0.950 Å cm⁻²</td>
<td>-0.857</td>
</tr>
</tbody>
</table>

We have not included the 1/f plots of 61000 and 85000 in the present discussion. These plots are just similar to Fig 5.24 except that the γ values are decreasing and tending to -1 for lower current densities and higher thickness.

5.7.1b. 1/f NOISE IN THIN FILMS OF COPPER SELENIDE ON GLASS SUBSTRATE AT DIFFERENT TEMPERATURES

1/f noises of 46000 Å copper selenide films on glass substrate are studied at different temperatures. As described in Chapter 4, temperatures of the thin films are maintained at 310 K, 335 K, 360 K, 385 K and 410 K by immersing the films in oil bath maintained at these temperatures. The temperatures are maintained using a PID controller by using a thermocouple as a sensor. The same thermocouple is used to measure the temperature of the DUT. The 1/f noise records so measured at these temperatures are plotted in Fig 5.25. It is observed that the absolute FFT levels are proportional to the thin film temperature, the current density being constant. The variation of dynamic resistance of the copper selenide film is plotted as a function of the film temperature in Fig 5.26. The resistance is nonlinearly decreasing with increasing temperature. For a semiconductor bulk material it is expected that the resistance exponentially fall with absolute temperature. In a limited temperature range of study the logarithm of
resistance of a bulk material when plotted as a function of inverse of temperature result into a straight line. However this law may not suit in the case of thin films as several investigators have reported deviations from the bulk materials. It would be interesting to investigate the variation of $\gamma$ as a function of temperature. The $-\gamma$ values are plotted as a function of temperature in Fig 5.25a.

It is quite interesting to note that the 1/f noise variations are closely following the resistance variation in copper selenide thin films on glass substrate. When the change in resistance is diminished for similar temperature range (please refer Fig 5.26 and Fig 5.28), the 1/f noise magnitudes are undergoing similar changes (please see Fig 5.25 and Fig 5.27).

Table 5.13 – Average Slopes of 1/f graphs in Copper Selenide Films of Thickness 46000 Å, 85000 Å and 104000 Å at Constant Current Density (10 A/cm²) and Different Temperatures on glass substrate

<table>
<thead>
<tr>
<th>SL. No.</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Temperature of the thin film</th>
<th>Average Slope $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.25</td>
<td>46000 Å Cu$_2$Se at different temperatures on Glass substrate</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.594</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.613</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.633</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.667</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.683</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.27</td>
<td>85000 Å Cu$_2$Se at different temperatures</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.611</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.614</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.628</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.663</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.688</td>
</tr>
<tr>
<td>3</td>
<td>Fig 5.29</td>
<td>104000 Å Cu$_2$Se at different temperatures</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.714</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.715</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.721</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.768</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.791</td>
</tr>
</tbody>
</table>
5.7.2 1/f NOISE IN THIN FILMS OF COPPER SELENIDE ON MICA SUBSTRATE AT DIFFERENT TEMPERATURES

As already stated thin films of copper selenide of thickness 10000, 46000, 61000 & 85000 Å are prepared on mica substrate at 10 Å/s deposition rates maintained at 2 x 10^{-3} mbar pressure. Separate films are grown at three different substrate temperatures (310 K, 360 K and 410 K) both for glass and mica substrates. We already pointed out that 1/f noise studied at different substrate temperatures behave almost similarly for a given substrate. There is no appreciable difference in noise recorded for films grown at different substrate temperatures on glass or mica.

1/f noise studies, as a function of current densities (at room temperature) reveal almost similar behaviour for glass as well as mica substrates. We have not presented the 1/f noise results of thin films on mica substrate at different current densities.

Fig 5.30, Fig 5.31, Fig 5.32 and Fig 5.33 are the 1/f plots of copper selenide of thickness 46000, 61000, 85000 and 104000 Å respectively. The studies are made at a constant current density and at 310K, 335 K, 360 K, 385 K and 410 K. However, most films on mica substrate exhibit higher magnitude of 1/f noise. The slope $\gamma$ as a function of frequency is much non-linear for films on mica substrate compared to similar films on glass substrate. A perusal Fig 5.31 clearly reveals the non-linear nature of 1/f graphs at all temperatures. The slope $\gamma$ is positive in
the frequency region 80 Hz to 200 Hz, \( \gamma \) becomes -0.3 between 300 Hz to 500 Hz, assumes a value of -0.5 in the range 500 Hz to 1 kHz and becomes less than -0.5 above 1 kHz, approaching to -1 around 10 kHz. We crosschecked the results by evaluating the mean deviations of the three individual trials of measurement. The deviations are found to be normal and compare well with deviations of other plots. The average slopes \( \gamma \) of the 1/f plots (evaluated from Figs 5.30, 5.31, 5.32 and 5.33), are presented in Table 5.15 for mica substrate. In the last column the glass substrate results are also included. The \( \gamma \) values are increasing with increasing temperature in accordance with the observations of literature values [8]. However, the averaged slopes estimated in the frequency region of 200 Hz to 8 kHz only are included in Table 5.15 for the mica substrate. These magnitudes of the slopes are plotted as a function of absolute temperature in Fig 5.30a for mica substrate for the four thickness studied in the present work.

Table 5.15 – Average Slopes of 1/f graphs in Copper Selenide Films of Thickness 46000 Å, 61000, 85000 Å and 104000 Å at Constant Current Density (10 A/cm²) and at Different Temperatures on mica substrate. \( \gamma \) values of glass substrate are compared in the last column.

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Temperature of the thin film</th>
<th>Average Slope ( \gamma )</th>
<th>( \gamma ) glass substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.30</td>
<td>46000 Å ( \text{Cu}_2\text{Se}) at different temperatures on Mica substrate</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.51</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.552</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.651</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.674</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.704</td>
<td>-0.722</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.31</td>
<td>61000 Å ( \text{Cu}_2\text{Se}) at different temperatures on Mica substrate</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.534</td>
<td>-0.594</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.52</td>
<td>-0.613</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.572</td>
<td>-0.633</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.574</td>
<td>-0.667</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.588</td>
<td>-0.683</td>
</tr>
<tr>
<td>3</td>
<td>Fig 5.32</td>
<td>85000 Å ( \text{Cu}_2\text{Se}) at different temperatures on Mica substrate</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.574</td>
<td>-0.611</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.639</td>
<td>-0.614</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.645</td>
<td>-0.628</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.697</td>
<td>-0.663</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.692</td>
<td>-0.688</td>
</tr>
<tr>
<td>4</td>
<td>Fig 5.33</td>
<td>104000 Å ( \text{Cu}_2\text{Se}) at different temperatures on Mica substrate</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.72</td>
<td>-0.714</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.747</td>
<td>-0.715</td>
</tr>
<tr>
<td></td>
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<td>Red</td>
<td>360 K</td>
<td>-0.792</td>
<td>-0.721</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.9</td>
<td>-0.768</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.906</td>
<td>-0.791</td>
</tr>
</tbody>
</table>
The results on noise measurements using mica as substrate are somewhat different from the results obtained using glass as substrate. The \( \gamma \) values derived for mica substrate are higher compared to those derived for glass substrate. This may be due to the micro-defects that are likely to be present on mica surface.

5.8 1/f NOISE IN THIN FILMS OF CADMIUM SELENI DE

Extra pure cadmium selenide of 99.999% purity is used to prepare the thin film on glass substrate maintained at 310 K. Cadmium selenide films of thickness 6000, 8000 and 10000 A° are deposited, on glass substrate, at 10 A/s deposition rates, maintained at 2 \( \times \) 10^{-5} mbar pressure.

5.8.1 1/f NOISE IN THIN FILMS OF CADMIUM SELENI DE ON GLASS SUBSTRATE AT VARIOUS CURRENT DENSITIES

1/f studies at different current densities are carried out on 8000 A° and 10000 A° films of cadmium selenide. It has not been possible to study the 6000 A° films due to instability resulted in device currents. Fig 5.34 is the 1/f noise results at current densities 5.75, 7.02, 9.9, 12.6, and 21 Acm\(^{-2}\) on 8000 A° film. The slope \( \gamma \) is gradually increasing with increasing current. As already confirmed for copper selenide, this behaviour seems to be a characteristic of
semiconductors and an opposite trend is observed in aluminium. The average value of $\gamma$ is presented in Table 5.16. It is interesting to note that two distinct values of $\gamma$ are clearly observed for each of the $1/f$ noise curve. The first slope exists in the range 200 Hz to 5000 Hz and the second slope exists above 6 kHz. The average values reported in Table 5.16, at S.No 1, for this thickness can be taken as low frequency values. The high frequency values about 30% to 40% higher than the values reported in Table 5.16. Abrupt change in slope is associated with simultaneous existence of double or higher mechanisms that give rise to $1/f$ noise. Conversely a single constant slope in the entire frequency range support the existence of a single unique mechanism that give rise to $1/f$ noise.

Fig 5.35 is the $1/f$ noise results at current densities 3.24, 4.08, 5.5, 8.43 and 18.1 Acm$^{-2}$ on 10000 A° film. The slope $\gamma$ is gradually increasing with increasing current. This behaviour is a characteristic of semiconductors. The average value of $\gamma$ is presented in Table 5.16 at S.No 2. It is noted that the value of $\gamma$ gradually changes to lower values at the higher frequencies, particularly for larger currents. At low currents the slope almost remains constant in the active frequency range. The spacing between any two curves is almost proportional to the differences of currents between the two curves.

Table 5.16 – Average Slopes of $1/f$ graphs in Cadmium Selenide Films of Thickness 6000 A°, 8000 and 10000 A° at Various Current Densities at 310 K on glass substrate

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Current Density in the thin film</th>
<th>Average Slope $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.34</td>
<td>10000 A° CdSe film at different current densities</td>
<td>Magenta</td>
<td>21.07 A cm$^{-2}$</td>
<td>-0.450</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>12.642 A cm$^{-2}$</td>
<td>-0.470</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>9.030 A cm$^{-2}$</td>
<td>-0.500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>7.023 A cm$^{-2}$</td>
<td>-0.550</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>5.746 A cm$^{-2}$</td>
<td>-0.623</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.35</td>
<td>8000 A° CdSe film at different current densities</td>
<td>Magenta</td>
<td>18.08 A cm$^{-2}$</td>
<td>-0.655</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>8.432 A cm$^{-2}$</td>
<td>-0.757</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>5.498 A cm$^{-2}$</td>
<td>-0.835</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>4.079 A cm$^{-2}$</td>
<td>-0.880</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>3.242 A cm$^{-2}$</td>
<td>-0.886</td>
</tr>
</tbody>
</table>

The $-\gamma$ values (average magnitude of $\gamma$) derived from Fig 5.34 are plotted as a function of current density in Fig 5.34a. The $\gamma$ values are increasing with increasing current. In a similar fashion the $-\gamma$ values derived from Fig 5.35 are plotted as a function of current density in Fig
5.35a. The $\gamma$ values are increasing with increasing current, supporting the behaviour as observed in literature [8] for metals and semiconductors.

Fig 5.34a - Current density $\text{Acm}^{-2}$ (x-axis) versus noise factor ($-\gamma$) in the range of study for Cadmium Selenide films of 8000 Å thickness on glass at 310K. The change in $\gamma$ with increasing current is positive in Copper Selenide.

Fig 5.35a - Current density $\text{Acm}^{-2}$ (x-axis) versus noise factor ($-\gamma$) in the range of study for Cadmium Selenide films of 10000 Å thickness on glass at 310K. The change in $\gamma$ with increasing current is positive in Copper Selenide.
5.8.2 1/f noise in thin films of cadmium selenide on glass substrate studied at film temperatures 310 K, 335 K, 360 K, 385 K and 410 K.

1/f noises of 10000 Å cadmium selenide films on glass substrate are studied at different temperatures. As described already, the temperatures of the thin films are maintained at 310 K, 335 K, 360 K, 385 K and 410 K by immersing the films in oil bath. The bath is maintained at these temperatures using a PID controller as cited in Chapter 4. The 1/f noise records so measured at these temperatures are plotted in Fig 5.36. It is observed that the absolute FFT levels are proportional to the thin film temperature. Even though the curves seemed to be clogged on using the zoom function, the entire details can be amplified. The current density is maintained constant for all the experimental plots. The variation of dynamic resistance of the 10000 Å cadmium selenide film is plotted as a function of the film temperature in Fig 5.37. The resistance is linearly decreasing with increasing temperature. For a bulk semiconductor the resistance is expected to fall exponentially, approaching the intrinsic value at higher temperature. This law generally deviates in the case of thin films in particular. The \(-\gamma\) values are plotted as a function of temperature in Fig 5.36a for both 8000 Å and 10000 Å thickness at constant current 5 mA in cadmium selenide film. Average \(\gamma\) values as derived from Fig 5.36 and Fig 5.38 are tabulated in Table 5.17:

It is quite interesting to note that the 1/f noise variations are closely following the resistance variation in cadmium selenide thin films on glass substrate.

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Temperature of the thin film</th>
<th>Average Slope (\gamma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.36</td>
<td>10000 Å CdSe at different temperatures</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.705</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.685</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.622</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.692</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.662</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.38</td>
<td>6000 Å CdSe at different temperatures</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.656</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.656</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.625</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.650</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.687</td>
</tr>
</tbody>
</table>
5.9. 1/f NOISE IN THIN FILMS OF TELLURIUM ON GLASS & MICA SUBSTRATE

Thin films of tellurium are grown on (i) glass substrate and (ii) mica substrate independently. The 4500, 6620 and 10180 Å thicknesses are prepared on glass substrate and mica substrate at 10 Å s⁻¹ deposition rates maintained at 2 x 10⁻⁵ mbar pressure. The substrate is maintained at 310 K.

5.9.1a 1/f NOISE IN THIN FILMS OF TELLURIUM ON GLASS SUBSTRATE AT VARIOUS CURRENT DENSITIES

The 1/f noise studies on tellurium of 10180 Å thickness maintained at room at current densities 2.52, 3.19, 4.0, 5.91 and 7.66 A cm⁻² yield -0.844, -0.785, -0.804, -0.755 and -0.777 respectively (please refer 5.40). Since the γ values increase with increasing current for the entire range of tellurium specimen at room temperature. We have presented only one set at 310 K for 10180 Å thickness. Specimen of other thickness also yields similar results and are not presented or discussed. The mean γ values evaluated from Fig 5.40 are presented in Table 5.18 and graphically presented in Fig 5.40a. The change in γ with increasing current is positive in Tellurium deposited on glass substrate at 310 K.
Table 5.18 – Average Slopes of 1/f graphs in Tellurium Film of Thickness 10180 Å at Various Current Densities at 310 K on glass substrate

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Figure</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Current Density in the thin film</th>
<th>Average Slope γ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.40</td>
<td>10180 Å Tellurium at different current densities</td>
<td>Magenta</td>
<td>7.666 A cm⁻²</td>
<td>-0.755</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>5.914 A cm⁻²</td>
<td>-0.777</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>4.007 A cm⁻²</td>
<td>-0.804</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>3.186 A cm⁻²</td>
<td>-0.795</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>2.524 A cm⁻²</td>
<td>-0.844</td>
</tr>
</tbody>
</table>

Fig 5.40a - Current density A cm⁻² (x-axis) versus noise factor (γ) in the range of study for Tellurium films of 10180 Å thickness on glass at 310K.

5.9.1b 1/f NOISE IN THIN FILMS OF TELLURIUM ON GLASS SUBSTRATE AT 310 K, 335 K, 360 K, 385 K AND 410 K.

1/f noises of 10180 Å tellurium films on glass substrate are studied at temperatures 310 K, 335 K, 360 K, 385 K and 410 K by immersing the films in oil bath. The bath is maintained at these temperatures using a PID controller as cited in Chapter 4. The 1/f noise records so measured at these temperatures are plotted in Fig 5.42. It is observed that the absolute FFT levels are proportional to the thin film temperature. The current density is maintained constant (5 A cm⁻²) at all the temperatures. The dynamic resistance of the 10180 Å tellurium film is found to be almost linear, decreasing with increasing temperature. Similar studies are made for 6620 Å tellurium film at constant current density (5 A cm⁻²), deposited on glass (310 K substrate temperature) and presented in Fig 5.43.
The \(-\gamma\) values obtained from Fig 5.42 and 5.43 are plotted as a function of temperature in Fig 5.42a. It is noted that the 1/f noise variations are closely following the resistance variation in tellurium thin films on glass substrate (this behaviour is observed for all semiconductor thin films studied in this work).

![Graph showing 1/f noise variations](image)

**Table 5.19** – Average Slopes of 1/f graphs in Tellurium Films of Thickness 6620 Å, and 10180 Å maintained at Constant Current Density (5 Acm\(^{-2}\)) and films maintained at Different Temperatures (deposited on glass substrate)

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Temperature of the thin film</th>
<th>Average Slope (\gamma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.42</td>
<td>10180 Å Tellurium at different temperatures deposited on glass substrate at 310 K</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.718</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.756</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.821</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.831</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.43</td>
<td>6620 Å Tellurium at different temperatures deposited on glass substrate at 310 K</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.752</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.763</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.768</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.777</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.78</td>
</tr>
</tbody>
</table>
5.9.2. 1/f NOISE IN THIN FILMS OF COPPER SELENIDE ON MICA SUBSTRATE AT DIFFERENT TEMPERATUES

1/f noises of 4590 A° tellurium films on mica substrate are studied at temperatures 310 K, 335 K, 360 K, 385 K and 410 K by immersing the films in controlled oil bath, as already indicated in the previous sections. The 1/f noise records so measured at these temperatures are plotted in Fig 5.44. It is observed that the absolute FFT levels are proportional to the thin film temperature, even though the curves are very close to each other. The trend can be observed clearly on zooming the plotted portions. The current density is maintained constant (5 A cm⁻²) at all the temperatures. The dynamic resistance of the 4590 A° tellurium film, as presented in Fig 5.45, is found to be linear, decreasing with increasing temperature.

1/f noises of 6620 A° tellurium films on mica substrate are studied at temperatures 310 K, 335 K, 360 K, 385 K and 410 K at constant current density (5 A cm⁻²). The films are deposited on mica at substrate temperature 310 K. The 1/f noises in tellurium are presented in Fig 5.46. The temperature versus dynamic resistance plot shows a linear behaviour as in Fig 5.47.

Table 5.20 – Average Slopes of 1/f graphs in Tellurium Films of Thickness 4590A°, and 6620 A° maintained at Constant Current Density (5 A cm⁻²) and films maintained at Different Temperatures (deposited on glass substrate)

<table>
<thead>
<tr>
<th>SL No</th>
<th>Figure number</th>
<th>Description</th>
<th>Colour of graph</th>
<th>Temperature of the thin film</th>
<th>Average Slope $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fig 5.44</td>
<td>4590 A° Tellurium at different temperatures on Mica</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.648</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.677</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.706</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.783</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.795</td>
</tr>
<tr>
<td>2</td>
<td>Fig 5.46</td>
<td>6620 A° Tellurium at different temperatures on Mica</td>
<td>Magenta</td>
<td>410 K</td>
<td>-0.719</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyan</td>
<td>385 K</td>
<td>-0.783</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td>360 K</td>
<td>-0.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>335 K</td>
<td>-0.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue</td>
<td>310 K</td>
<td>-0.855</td>
</tr>
</tbody>
</table>

The ($\gamma$) values obtained from Fig 5.44 and 5.46 are plotted as a function of temperature in Fig 5.44a. It is noted that the 1/f noise variations are closely following the resistance...
variation in tellurium thin films on glass substrate (this behaviour is observed for all semiconductor thin films studied in this work).

![Graph](image)

Fig 5.44a - The (-y) values are plotted as a function of temperature for 4590 A° (black), and 6620 A° (magenta) [deposited on mica substrate]

The 1/f noise of tellurium of 6620 A° thickness films on glass substrate (presented in Fig 5.43) and of same thickness on mica substrate (presented in Fig 5.44) can be compared to visualise the differences in measured 1/f noise. A perusal and comparison of Fig 5.43 and 5.44 are almost alike in shape and trend except that the scatter in noise magnitudes are a bit higher for Fig 5.44.

5.10 GENERAL CONCLUSIONS DERIVED FROM 1/f NOISE STUDIES IN THIN FILMS

A review of the recent studies in thin films of metals and semiconductors is presented in Sec 5.1. A critical analysis of the historical developments is yet to be presented. We have already provided references ranging from 1 to 66 in Table 5.2. To avoid duplication these references are accounted in that order and additional references are appended. Please refer Table 5.2 for references up to 66 and the list appended at end of this chapter for the remaining references (from 67 onwards).

Kotera et al [70] have studied 1/f noise in InSb thin films of 2 μm thickness at room temperature. Noise intensity is inversely proportional to the number of electrons in the bulk. The temperature rise of specimen due to joule heating does not affect the noise intensity.
The noise intensity coefficient settles to a constant by repeated heat treatments. The coefficient is independent of the doped impurity concentration. The noise voltage is linearly dependent on the bias current.

Voss and Clarke [97] presented experimental evidence that 1/f noise in metals and semiconductors is an equilibrium phenomenon. The simplest version of the non-linear equilibrium theory of 1/f noise predicts $f^\gamma$ with $\gamma$ value equal to 0.5 (in the singular frequency region which is quite different from the 1/f region), which falls in the low frequency region. Let the singular frequency region exist below $f_s$ Hz. $\gamma = 1$ for bulk materials for frequencies that fall above a $f_h$ value as defined by Voss and Clarke [95]. Mikulinsky [71] cites that, the usual experimental region falls in between these values $f_s$ and $f_h$ with a limit $0.5 < \gamma < 1$. At low temperature of the order of $T = 100$ K, the singular frequency region may fall in the normal region of study 10 Hz to 200 Hz.

The 1/f noise studies of Hooge [98] and Vandamme [100] were based on the so called Hooge’s eqn 5.1. For a given material C is constant. Actually $C = A B$ where $A = 2 \times 10^{-3}$, an independent constant for all material under study (bulk or thin film) and B is a material dependent constant which depends on the physical properties of material under study. Generally in all earlier studies $\gamma = 1$ was assumed, based on the Hooge’s eqn 5.1, B of the material was evaluated from the physical properties and an attempt was made to determine A. Voss and Clarke [95] made the first deviation by determining $\gamma$, in turn using it to evaluate A. Their results proved that A differs by five to ten folds in semi-metal bismuth. Eberhard and Horn [98] showed that 1/f noise is temperature dependent and eqn 5.1 can’t be universal in nature as pointed by Dutta and Horn [74].

Hooge and Hoppenbrouwers [1] studied the thin films of gold of variable thickness and suggested that average power spectral density is inversely proportional to the thickness while it is proportional to $f^{-\gamma}$, where $\gamma$ was shown to be in the 0.9 to 1.4 ranges. Since high current densities and small samples were used the noise recorded should have been the surface noise rather than bulk noise. Celasco, Florello, Masoero [99] first suggested that noise in continues metal films originates at the interface between the films and substrate. Noise in thin films is a universal feature of the metal-substrate interface. The noise was shown to be proportional to $t^2$ ($t$ is the thickness of the film).
However, it is established in metals that 1/f noise do not depend much on substrate. In semiconductors the 1/f noise is proposed to depend very much on the surface states rather than the bulk states. It is likely that eqn 5.1 may fail in semiconductors as visualized by Hooges [98].

The basic requirement of all 1/f noise studies is the noise present should be measured under equilibrium condition. The noise power should be proportional to square of the noise voltage, $V^2$ (or $I^2 R^2$), under equilibrium condition. It is actually found that noise power is proportional to $V^{2+\beta}$, where $\beta > 0$. It is expected that log $S_V$ versus log (dR/dt) is expected to be linear with positive slope. To observe the singular behaviour of $1/f^x$, one is expected to study the power spectral behaviour in bulk at lower temperatures of the order 100 K in metals. Normal 1/f behaviour is observed in bulk at room temperature or in thin films in which the bulk states predominates the surface states. That is, the surface state predominance is expected in much thinner films. Similarly the small current densities would tend to normal 1/f behaviour and excess currents would result in to hopping current conduction increasing the value of the slope $\gamma$.

Noise power spectrum measurements on a conductor are a sensitive tool to detect any structural defects, localized state and local charge modulations if any. Koch et al [79] suggested that the equilibrium motion of atoms, causes 1/f noise in aluminium films. 1/f noise low frequency region of the order of below 1 Hz was investigated.

de Graff and Huybre [75] observe that with reference to eqn 5.1 the $A$ value evaluated from studies on polycrystalline silicon resistors indicate at low doping level $A=4 \times 10^3$. At higher doping levels $A$ decreases as $(\mu/\mu_{lat})^2$ supporting the statement that this type of scattering is due to lattice scattering. By adopting Kleinpenning model [72], it is assumed that the 1/f noise arise in depletion regions of the grains and grain boundaries do not contribute to 1/f noise.

Eugene [76] points out that electronic mobility in ion implanted samples is lower than that in a low-pressure chemically deposited samples because of the strains in the former. It is observed that the power relation that holds linearity is $1^{1.6}$ instead $I^2$ as required by Hoog’s model [98].

Neri et al [81] expect that the noise power spectrum measurements on a conductor are a sensitive tool to detect any structural defects, localized state and local charge modulations if
any. Koch et al [79] suggested that the equilibrium motion of atoms causes 1/f noise in aluminium films. 1/f noise low frequency region of the order of below 1 Hz was investigated.

Shu [82] cites the conclusion arrived by Hooge and Hoppenbrouwers through 1/f noise is in gold films. The noise is inversely proportional to the total number of electrons and is of same order as in a semi-conductor [1]. Two distinct 1/f noise models have been presented so far. The first one is the carrier density fluctuation model (or surface states model) [83] and the 2nd model is the carrier mobility fluctuation model (or bulk model) [98 and 100]. Shu [82] studied 1/f noise in chromium silicide using an integrated approach by combing the entirely different ideas of Hooge's [98] and Voss & Clarke [97].

The studies of Belan and Mikolaj [85] in metals revealed agreement of 1/f noise according to Hooge’s relation [98] in bismuth and manganese and disagreement in certain other metallic thin films.

The basic requirement of all 1/f noise studies is the noise present should be measured under equilibrium condition. The noise power should be proportional to square of the noise voltage, $V^2$ (or $I^2 R^2$), under equilibrium condition. It is actually found that it is proportional to $V^{2-\beta}$, where $\beta > 0$. It is expected that log Sv versus log (dR/dt) is expected to be linear with positive slope. To observe the singular behaviour of $1/f^{0.5}$, one is expected to study the power spectral behaviour in bulk at lower temperatures of the order 100 K in metals. Normal 1/f behaviour is observed in bulk at room temperature or in thin films in which the bulk states predominates the surface states. That is, the surface state predominance is expected in thinner films. Similarly the small current densities would tend to normal 1/f behaviour and excess currents would result in to hopping current conduction increasing the value of the slope $\gamma$.

The most important conclusions derived in the above discussion are are presented below:

1. 1/f noise is inversely proportional to the total number of electrons [1].
2. The magnitude of the 1/f noise in aluminium is found to increase rapidly in the range of Temperature between 90 and 350K [4].
3. Presence of Hydrogen was found to alter the electrical properties of gold (Au) films.
4. The enhanced 1/f noise in metals comes from tunnelling process within weak links, not from the temperature fluctuation (dR/dT). [26]
5. 1/f noise implicates a dual conduction mechanism for composites combining noisy tunnelling and quiet metallic paths. [19]
6. The stepwise increase in noise in metallic films affected the electro migration and is attributed to highly mobile defects, this do not contribute significantly to resistance [20].

7. 1/f noise study can be regarded as a non-destructive test to check interconnections in VLSI circuits [16] and [17].

8. The 1/f noise of gold and aluminium films increases in proportion to the fifth power of resistance in the high resistance range and to the cube of the resistance in the low resistance range [8] and [20].

9. Intrinsic 1/f noise is much larger than metallic films and is consistent with the fluctuation-dissipation theorem and magnetization fluctuations in the ferromagnetic phase [39 and 41].

10. 1/f noise promises to be an early indicator of VLSI damage [36].

11. 1/f noise measurements are a sort of non-destructive technique for testing devices based on large-scale integration and the interconnections made using aluminium interconnections [47].

12. In InSb the noise voltage is linearly dependent on the bias current [70].

13. A limit $0.5 < \gamma < 1$ is sometimes observed for thin films studied below room temperature [71].

14. Dutta [74] points that Hooge’s eqn 5.1 [98] predict that $C = A B$ where $A \equiv 2 \times 10^{-3}$ for most materials and $B$ is a constant for a given material.

15. de Graff and Huybre [75] observe that with reference to eqn 5.1 the ‘A’ value evaluated from studies on polycrystalline silicon resistors is $4 \times 10^{-3}$. At higher doping levels A decreases as $(\mu/\mu_{lattice})^2$ supporting the statement that this type of scattering is due to lattice scattering.

16. Eugene [76] points out that electronic mobility in ion-implanted samples is lower than that of a low-pressure chemically deposited samples because the strains are found in the ion-implanted materials. The power spectral density obeys $1/\nu$ instead $1/\nu^2$.

17. Neri et al [81] expected that the noise power spectrum measurements on a conductor are a sensitive tool to detect any structural defects, localized state and local charge modulations if any.

18. Koch et al [79] pointed that the equilibrium motion of atoms causes 1/f noise in aluminium films. 1/f noise in very low frequency region below 1 Hz is investigated.

19. The 1/f noise is inversely proportional to the total number of electrons and is of the same order in a semi-conductor [1].

20. The carrier mobility fluctuation model (or bulk model) [98 and 100] is better than the carrier density model [83] to explain the 1/f noise in semi-conductors.

The noise power should be proportional to square of the noise voltage, $V^2$ (or $I^2 R^2$), under equilibrium condition. It is actually found that it is proportional to $V^{2 + \beta}$, where $\beta > 0$.

5.11 DISCUSSION ON PRESENT 1/f NOISE STUDY

1. Fig 5.4 to 5.11 indicates that in aluminium thin films the magnitude of noise is increasing while $\gamma$ is decreasing with increasing current density. The slope $\gamma$ evaluated by various workers was reported to be constant.
It is noticed that for a constant current, decreasing the thickness of the film lead to an increase of the $\gamma$ value in aluminium. This is in agreement with literature observations [3, 10, 19 and 20].

For silver and gold $\gamma$ is a constant when current density is changed. When constant current is maintained in films of different thickness, the $\gamma$ value is observed to remain constant in silver. In gold thin films the $\gamma$ is found to decrease with increasing thickness. In silver thin films the $\gamma$ is found to be almost constant with increasing thickness. As the thickness of the film is increased, the $1/f$ properties of the bulk material are attained [20, 33 and 49].

It is observed that $\gamma$ values recorded in the present work for metals are in the range $-0.5$ to $-0.82$. The magnitude of the $1/f$ noise is highest in aluminium. The thin films of gold show higher noise amplitudes compared to silver. Figures (5.21 and 5.22) show that $1/f$ noise variations for aluminium $>\text{gold} >\text{silver}$ (considering equal thickness and current densities). The electrical resistivities of aluminium, gold and silver are $2.65 \times 10^{-8}$, $2.4 \times 10^{-8}$ and $1.6 \times 10^{-8}$ $\Omega$m respectively.

The thin films of copper selenide (of certain thickness) grown on glass at different substrate temperatures 310 K, 360 K and 410 K show constant $\gamma$ values when constant current is maintained in the films.

Even though the $\gamma$ values for films coated on mica substrate show higher noise compared to films on glass substrate (other conditions being same in the two kinds of films), the films grown on mica at 310 K, 360 K and 410 K temperatures exhibit same $\gamma$ values.

In view of comments 5 and 6 we restrained our detailed studies to copper selenide films grown on glass and mica at 310 K only.

Thin films of copper selenide grown on glass and mica substrates at 310 K show that as current density is increased, the $\gamma$ values also increase, and tend to $-1$ as current density tends to zero.

The $\gamma$ value is increasing with increasing temperature for all the copper selenide films when constant current is maintained in the film. The $\gamma$ value tends to the $1/f$ value ($-1$) as the temperature is reduced. The $\gamma$ value is increasing with decreasing
thickness and tends to \(-1\) for thicker specimens of copper selenide. The settling down of \(\gamma\) to \(-1\) for higher thickness is expected since the higher thickness films are likely to yield most of the physical properties in bulk.

9. The cadmium selenide films grown on glass substrate show that the magnitude of noise is increasing with increasing current. However, the films exhibit certain deviations from the behaviour as recorded for other thin films. The higher thickness film, 10000 Å show larger values of \(\gamma\) compared to lower thickness film of 8000 Å. The increase in temperature of the film resulted into a decrease of \(\gamma\) value, an opposite behaviour compared that of the copper selenide. The temperature as well as the thickness dependence of \(\gamma\) is opposite compared to the copper selenide films.

10. The tellurium films grown on glass and mica substrates are behaving in a parallel manner when compared to copper selenide films when the \(1/f\) noise behaviour is compared.

11. The most important conclusion is that for most of the thin films of metals and semiconductors the \(\gamma\) values recorded are in the range of \(-0.6\) to \(-0.9\) which are higher than the literature values of \(-1\) to \(-1.4\). In all our measurement we have corrected for the extraneous background noise. The most probable reason for the higher values of \(\gamma\) is that large white noise is present in the device.

Fig 5.51 - To test this aspect we simulated the \(1/f\) noise using a Microsoft Excel sheet. Fig 5.51 is a plot for a unit noise input, in the frequency region of 20 Hz to 20 kHz, with an absolute gain of \(10^5\), Series 1 depends as \(f^{0.5}\) and series 2 as \(f^1\).

Fig 5.52 - An additional constant white noise of absolute magnitude 0.01, which on amplification turns to \(10^3\), is introduced to observe the resulting changes in \(1/f\) noise. This noise is introduced only in the \(1/f\) noise (series 2). It is clearly seen in Fig 5.52 that the \(f^{0.5}\) plot is of the same order as that of \((f^1 + \text{white noise})\) presented as series 2.

This amply explains the possibility of white noise being present in the thin films studied in the present work, since observed values of \(\gamma\) are almost coinciding in the high current or low thickness regions of the films studied in the present work. Moreover the slight inward inflexions observed in Figs 5.4 to 5.20 can be explained.
Another important characteristic present in certain Figs 5.23, 5.25, 5.27, 5.29 to 5.42 have to be explained. Most of these curves have a convex shape (which is opposite to that discussed in the previous point of observation 11). On simulation, it is found that this characteristic is due to probable error introduced in the frequency term. The situation requires a frequency correction. An error in frequency is purposefully introduced. An error in frequency of \( f_{cor} \) (\( f_{cor} = 100 \) Hz for Fig 5.53) is purposefully introduced. We shall call this frequency as observed frequency.

The correction factor for observed frequency is tested in the following manner. On using observed frequency, series 1 is obtained. On applying correction for frequency term, by replacing \( f \) with \( f - f_{cor} \), series 2 is resulted. Series 2 is the corrected \( 1/f \) noise behaviour while series 1 is the observed behaviour in which frequency term has an inherent error.

The same logic can be applied to correct the errors associated with Figs 5.23, 5.25, 5.27, 5.29 to 5.42 (all these figures look like series 1 of Fig 5.53). To correct the situation frequency correction has to be made by replacing all the frequency terms \( f \) by \( f - f_{cor} \). The corrected series 1 is hence resulted by correcting for the frequency term. It has been found that \( f_{cor} \) terms for the above figures are of the order of 20 Hz to 45 Hz. On applying these corrections, the \( \gamma \) values are reduced by 4% to 9% depending on \( f_{cor} \) term. These magnitudes of these corrections are double the absolute value of the estimated error. The \( \gamma \) values are to be accordingly corrected.
Fig 5.51 – Simulated $f^{0.5}$ (series 1) and $f^1$ (series 2) noise plots for a unit input at a total gain of $10^5$.

Fig 5.52 – Simulated $f^{0.5}$ (series 1) and $f^1$ noise plus a 0.01 additional white noise (series 2) along with a unit 1/f input at total gain of $10^5$. 
Fig 5.53 - Simulated and 1/f noise after adding a correction of 100 Hz to the
total gain of 10^3.
Table 5.1 – Benchmark publications on 1/f Noise Studies in Metallic and Semiconductor Thin Films

<table>
<thead>
<tr>
<th>Ref No</th>
<th>Authors</th>
<th>Title of the Publication</th>
<th>Journal</th>
<th>Summary in brief</th>
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<tbody>
<tr>
<td>1</td>
<td>Hooge-FN; Hoppenbrouwers-AMH</td>
<td>1/f noise in continuous thin gold films</td>
<td>Physica. vol.45, no.3; 1969; p.386-92</td>
<td>1/f noise is in gold is inversely proportional to the total number of electrons and is of same order as in a semi-conductor.</td>
</tr>
<tr>
<td>2</td>
<td>Lilly-AC-Jr; Henderson-RM; Sharp-PS</td>
<td>Thermally stimulated currents in Mylar, high-field low-temperature case</td>
<td>Journal-of-Applied-physics vol.41, no.5; April 1970; p.2001-6</td>
<td>The spectrum at low temperature is characterized by 1/f noise arising possibly from 'slow' surface states.</td>
</tr>
<tr>
<td>3</td>
<td>Tunailey-JKE</td>
<td>A physical process for 1/f noise in thin metallic films</td>
<td>Journal-of-Applied-Physics. vol.43, no.9; Sept. 1972; p.3851-5</td>
<td>1/f noise in thin films can be explained by a stochastic model chosen in which the conduction takes place by a tunnelling mechanism between small islands of conductivity.</td>
</tr>
<tr>
<td>4</td>
<td>Eberhard-JW; Horn-PM</td>
<td>Temperature dependence of 1/f noise in silver and copper</td>
<td>Physical-Review-Letters. vol.39, no.10, 5 Sept. 1977; p.643-6</td>
<td>The magnitude of the noise is found to increase rapidly with Temperature between 90 and 350K.</td>
</tr>
<tr>
<td>5</td>
<td>Kleinpenning-TGM; Vandamme-LKJ</td>
<td>Comment on 'Transverse 1/f noise in InSb thin films and the signal-to-noise ratio of related Hall elements'</td>
<td>Journal-of-Applied-Physics. vol.50, no.8; Aug. 1979; p.5547</td>
<td>In InSb thin-film Hall elements can be interpreted with existing 1/f noise calculations on four-probe configurations.</td>
</tr>
<tr>
<td>6</td>
<td>Kilmer-J; van-Vliet-KM; Chenette-ER; Handel-PH</td>
<td>Temperature response and correlation of 1/f noise in transistors</td>
<td>Sixth International Conference on Noise in Physical Systems (NBS-SP-614). NBS, Washington, DC, USA; 1981; x+416 pp. pp.151</td>
<td>concluded that the measured 1/f noise in transistors could not have been due to temperature fluctuations of the transistors or the substrate.</td>
</tr>
<tr>
<td>8</td>
<td>Takagi-Keiji; Toru Mizunami; Satoshi Masuda</td>
<td>1/f noise measurement in Semicontinuous Metal films</td>
<td>IEEE Trans-Components, Hybrids and manufacturing Technology. vol. CHMT – 12, no.4; Dec 1987; p.687-9</td>
<td>The 1/f noise of gold and aluminum films increases in proportion to the fifth power of resistance in the high resistance range and to the cube of the resistance in the low resistance range.</td>
</tr>
<tr>
<td>9</td>
<td>Ursutiu-D; Dogariu-A</td>
<td>Photonoise effect in thin films</td>
<td>Revue-Roumaine-de-Physique. vol.33, no.8; 1988, p.1213-16</td>
<td>It was found that the absorption of the chopped light perturbs the 1/f noise in a frequency range near the chopped frequency.</td>
</tr>
<tr>
<td>10</td>
<td>Rodbell-KP; Ficalora-PJ</td>
<td>The role of hydrogen in altering the electrical properties of gold, titanium, and tungsten films</td>
<td>Journal-of-Applied-Physics. vol.65, no.8; 15 April 1989; p.3107-17</td>
<td>Hydrogen was found to alter the electrical properties of gold (Au), titanium (Ti), and tungsten (W) thin films.</td>
</tr>
<tr>
<td>11</td>
<td>Jones-B-K; Mzunzu-E-S-C</td>
<td>Stability of polycrystalline silicon thin film resistors measured using excess noise.</td>
<td>Microelectron-Reliab. v 29 n 4 1989, p 543-544</td>
<td>the variations of resistance are compared with the magnitude and variations of the excess, 1/f noise which is known to be an equilibrium resistance fluctuation. The noise is found to be sensitive to the state of the specimen.</td>
</tr>
<tr>
<td>12</td>
<td>Nakao-M</td>
<td>Prospects for electronic applications of rare-earth-free superconducting thin films</td>
<td>Advances in Superconductivity. Proceedings of the 1st international Symposium on Superconductivity. Springer-Verlag, Tokyo, Japan; 1989; xxiii+920 pp.p.685-9</td>
<td>The SQUID operation observed up to 95 K in TCBCO shows promise for early applications of the films provided that 1/f noise can be reduced</td>
</tr>
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<td>13</td>
<td>Luo-Min-Yih; Bosman-Gijis</td>
<td>Analytical model for 1/f noise in polycrystalline silicon thin films</td>
<td>IEEE-Trans-Electron-Devices. v 37 n 3 pt 1 Mar 1990, p 768-774</td>
<td>It is concluded from the bias dependence and the magnitude of the noise density that the 1/f noise in polysilicon is depletion-region dominant</td>
</tr>
<tr>
<td>14</td>
<td>Liou-D-M; Gong-J; Chen-C-C</td>
<td>1/f noise spectrum derived from electromigration-induced resistance change</td>
<td>Jpn-J-Appl-Phys-Part-1. v 29 n 7 Jul 1990, p 1283-1285</td>
<td>The measured noise shows 1/f noise and the results were analyzed quantitatively with the derived model</td>
</tr>
<tr>
<td>15</td>
<td>Cottle-James-G; Klonaris-N-S; Bordelon-Mark</td>
<td>Symposium on Metallizations for Electronics Applications</td>
<td>Journal-of-Electronic-Materials. vol.19, no.11; Nov. 1990;</td>
<td>microstructural effects on the 1/f noise of thin Al based films; electromigration induced failures in interconnects with bimodal grain size distributions</td>
</tr>
<tr>
<td>16</td>
<td>Celik-Butler-Zeynep; Yang-Wiyi; Hoang-Hoang-H; Hunter-William-R</td>
<td>1/f super alpha noise and fabrication variations of TiW/Al VLSI Interconnects</td>
<td>IEEE-Electron-Device-Lett. v 11 n 11 Nov 1990, p 523-525</td>
<td>Nondestructive 1/f noise measurements were able to discriminate relative film group reliabilities and correlated with results of (MTF)</td>
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<tr>
<td>17</td>
<td>Celik-Butler-Zeynep; Yang-Wiyi; Hoang-Hoang-H; Hunter-William-R</td>
<td>Characterization of electromigration parameters in VLSI metallizations by 1/f noise measurements.</td>
<td>Solid-State-Electron. v 34 n 2 Feb 1991, p 185-188</td>
<td>Contrary to the 1/f^2 form it is observed 1/f noise spectra γ varied between 0.8 and 1.5. Through the Arrhenius plot of noise power spectral density</td>
</tr>
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<td>18</td>
<td>Lacoc-R-C; Hurrell-J-P; Springer-K; Raistrick-I-D; Hu-R; Burch-J-F; Simon-R-S</td>
<td>Low frequency 1/f noise measurements in YBa sub 2Cu sub 3O sub 7 thin films and the implications for HTS IR detectors.</td>
<td>IEEE-Transactions-on-Magnetics. v 27 n 2 pt 1V Mar 1991, p 2832-2835</td>
<td>The resistance fluctuations are interpreted as arising from two different mechanisms; a weakly temperature-dependent contribution which is dominant above the superconducting transition, and a strongly temperature-dependent contribution which dominates at the transition</td>
</tr>
<tr>
<td>19</td>
<td>Liou-D-M; Gong-J; Chen-C-C</td>
<td>Electromigration effect on low frequency noise in Al thinfilms.</td>
<td>Jpn-J-Appl-Phys-Part-1-Regular-Pap-Short-Note. v 30 n 4 Apr 1991, p 708-710</td>
<td>The change in the noise spectrum was used to characterize the electromigration damage of aluminum thin-film resistors</td>
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<td>20</td>
<td>Yang-Wiyi; Celik-Butler-Zeynep</td>
<td>Model for electromigration and low-frequency noise in thin metal films.</td>
<td>Solid-State-Electron. v 34 n 8 Aug 1991, p 911-916</td>
<td>Through this model the shape of the experimentally observed low-frequency spectra, the current dependence of the noise magnitude and the frequency exponent gamma , as well as the temperature dependence of gamma can be accurately explained</td>
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<tr>
<td>21</td>
<td>Yeh-WJ; Yu-LK; Yang-M; Song-LW; Kao-YH</td>
<td>Flux-flow noise and possible self-organized criticality in YBa sub 2Cu sub 3O sub 4 thin films</td>
<td>Physica-C. vol.195, no.3-4; 1 June 1992, p.367-72</td>
<td>A 1/f type noise was observed in the thermally activated depinning region providing a possible signature for self-organized criticality</td>
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<td>22</td>
<td>Celik-Butler-Zeynep, Ye-Min</td>
<td>Prediction of electromigration failure in W/Al-Cu multilayered metallizations by 1/f noise measurements.</td>
<td>Solid-State-Electron v 35 n 9 Sep 1992, p 1209-1212</td>
<td>The purpose of the study was to establish a correlation between the mean-time-to-failure (MTF) and low-frequency noise - magnitude and spectral shape - observed in these thin films.</td>
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<td>23</td>
<td>Lewandowski-SJ</td>
<td>Series Josephson junctions and transport properties of high-Tc superconductors</td>
<td>Proceedings of the International Workshop on Critical Current Limitations in High temperature Superconductors. World scientific, Singapore; 1992; xiii+396 pp.352-9</td>
<td>excessive 1/f noise and spurious modulation of the critical current by the applied magnetic field is observed.</td>
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<td>24</td>
<td>Kawahara-T; Hirai-A; Terashima-T; Bando-Y</td>
<td>Low frequency noise from YBa2Cu3O7-δ, thin films</td>
<td>Noise in Physical Systems and 1/f Fluctuations. IOS Press, Amsterdam, etheletics; 1992; xvi+752 pp.p.35-8</td>
<td>The low frequency noise power spectrum from high temperature superconducting thin films with grain boundaries show excess 1/f type noise.</td>
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<td>25</td>
<td>Bulashenko-OM; Kochelap-OV; Kochelap-VA</td>
<td>Noise redistribution in thin films due to electron scattering at the boundaries</td>
<td>Solid-State-Electronics. vol.36, no.1, Jan. 1993; p.111-13</td>
<td>It is observed that the noise redistributes towards higher frequencies by diminishing film thickness and decreasing surface specularity. The noise spectral density for a thin film is not Lorentzian unlike that for an unbounded sample.</td>
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<td>26</td>
<td>Lin-CL; Chi-CC. Chen-CC; Wu-MK</td>
<td>1/f noise near the superconducting transition of YBa2Cu3Ox meandering line-pattern thin film</td>
<td>Chinese-Journal-of-Physics. vol.31, no.6, pt.2, Jan. 1993; p.1073-8</td>
<td>The enhanced 1/f noise comes from tunneling process within weak links, not from the temperature fluctuation (dR/dT).</td>
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<td>27</td>
<td>Jiang-S; Hallemcier-P; Surya-C; Phillips-JM</td>
<td>Low-frequency excess noise in YBCO thin films near the transition temperature</td>
<td>AIP-Conference-Proceedings. no.285; 1993; p.119-22</td>
<td>The experimental results provide strong evidence that the low frequency excess noise in the device originated from equilibrium temperature fluctuations.</td>
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<td>28</td>
<td>Cottle-JG</td>
<td>Interpretation of current induced noise for detection of ULSI/VLSI interconnection reliability problems</td>
<td>Proceedings-of-the-SPIE --The-International-Society-for-Optical-Engineering. vol.1805; 1993; p.284-94</td>
<td>Importance of maintaining waveform stationarity when using 1/f noise to detect electromigration is illustrated. In addition, non-stationary waveforms, associated with thin films with high degrees of stress are reported.</td>
</tr>
</tbody>
</table>
Pronounced changes in low-frequency noise power spectra have been observed, close to the transition temperature, in current biased high-T sub-c superconducting thin films.

The origin of the noise in the normal state is believed to be due to thermal fluctuation or resistance fluctuation and the larger noise near zero T sub-c is possibly caused by grain boundaries.

The temperature dependence and annealing behaviour of 1/f noise may be understood in terms of thermally activated motion of defects in a distorted lattice potential.

Magnitude and frequency exponent for excess electrical noise spectra of 1/f were measured as a function of the Al-thin film temperature.

An one-dimensional model for explaining the 1/f noise in graphite and metal film resistors samples is studied. Which is based on the spontaneous temperature fluctuation of the small conducting spots in the samples and thermal conduction in a semi-infinite exponentially tapered solid.

The noise spectral density was found to be in the form of 1/F with 0.95 < y < 1.15, which corresponds to 1/f noise.

1/f noise promises to be an early indicator of VLSI damage.

As the resistivity reaches its maximum, the 1/f noise level increases exponentially with decreasing temperature, above that temperature, it is almost temperature independent.

The stepwise increase in noise is attributed to the creation of highly mobile defects, which do not contribute significantly to resistance.

At strong magnetic fields, the 1/f noise parameter is of the same order of magnitude as in nonmagnetic metal layers (Au, Cu, ...).
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<td>207</td>
<td>Cho-N-I; Nam-HG; Yu-SJ</td>
<td>Microscopic mechanism of electrical noise in Co/Si thin film structures</td>
<td>Japanese Journal of Applied Physics, Part 2: Letters, v. 35 n. 6A</td>
<td>The variation of the noise parameter is assumed to be an indication of the phase transformation along the nucleation reaction path in a Co/Si thin film system.</td>
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<td>41</td>
<td>Ailers-GB; Ramirez-AP; Jin-S</td>
<td>1/f resistance noise in the large magnetoresistance manganites</td>
<td>Applied Physics Letters, v. 68, n. 25</td>
<td>Intrinsic 1/f noise is much larger than metallic films and is consistent with the fluctuation-dissipation theorem and magnetization fluctuations in the ferromagnetic phase.</td>
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<td>42</td>
<td>Abkemeier-KM; Grier-DG</td>
<td>Topological disorder and conductance fluctuations in thin films</td>
<td>Physical Review B (Condensed Matter), v. 54, n. 4</td>
<td>The magnitude of conductance fluctuations in the networks caused by removal of single resistors in simulated resistor networks is found to scale with disorder parameter (s).</td>
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<td>44</td>
<td>Zhu-JW; Montress-GK; Greer-JA; Andres-D; Parker-TE</td>
<td>The influence of transducer metalization on SAW resonator electrical performance</td>
<td>1996 IEEE Ultrasonics Symposium Proceedings (Cat. No.96CH35993). IEEE, New York, NY, USA, 1996; 2 vol. 1622 pp.</td>
<td>The experimental techniques provide the basis for further investigations into the source of flicker (1/f) noise in SAW resonator devices.</td>
</tr>
<tr>
<td>46</td>
<td>Gingl-Z; Pennetta-C; Kiss-LB; Reggiani-L</td>
<td>Biased percolation and abrupt failure of electronic devices</td>
<td>Semiconductor Science and Technology, v. 11 n. 12 Dec</td>
<td>With 1/f noise it can be shown that biased percolation efficiently simulates degradation of thin films in good agreement with available experiments and predicts several features that should take place close to the abrupt failure of most devices.</td>
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<td>47</td>
<td>VanDamanne-LKJ; Vankaemenade-AJ</td>
<td>Resistance noise measurement: A better diagnostic tool to detect stress and current induced degradation</td>
<td>Microelectronics and Reliability, v. 37 n. 1 Jan</td>
<td>1/f Noise measurement can be used as a fast and non-destructive technique for reliability testing of LSI AI interconnects.</td>
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<tr>
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<tr>
<td>48</td>
<td>Ho-WY; Surya-Charles</td>
<td>Study of 1/f noise in hydrogenated amorphous silicon thin films</td>
<td>Solid-State-Electronics: An-International-Journal. v 41 n 9 Sep 1997, p 1247-1249</td>
<td>The experimental data provide strong evidence that the flicker noise originates from hydrogen motion within the material. The process appears to cause fluctuations in the device conductance by modulating the percolation path of the carriers.</td>
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<td>49</td>
<td>Van-Den-Homberg-Marcel; Alkemade-PFA; Verbruggen-AH; Dirks-AG; Ochs-E; Raelaar-S</td>
<td>Electromigration and 1/f noise in single-crystalline, bamboo and polycrystalline Al lines</td>
<td>Polycrystalline-Thin-Films-Structure.-Texture.-Properties.-Applications-Materials-Research-Society-Symposium-Proceedings. v 472 1997, MRS, Warrendale, PA, USA. p 307-312</td>
<td>The relation between electromigration and microstructure for three types of Al lines with different microstructures has been studied.</td>
</tr>
<tr>
<td>52</td>
<td>Hashiguchi-Sumihisa; Yamagishi-Yutaka; Fukuda-Toshiyuki; Ohki-Makoto; Sikuia-Josef; Vasina-Petr</td>
<td>Generation of 1/f spectrum by relaxation process in thin film resistors</td>
<td>Quality-and-Reliability-Engineering-International. v 14 n 2 Mar-Apr 1998, p69-71</td>
<td>Relaxation processes with various time constants generate a 1/f spectrum when they are driven by a single random time series and may be the origin of the noise in some thin film resistors.</td>
</tr>
<tr>
<td>53</td>
<td>Ichihara-Tsutomu; Aizawa-Kouichi</td>
<td>1/f Noise in a-Si_{1-x}C_{x}H thin films as novel thermistor materials for micromachined IR sensors</td>
<td>Journal-of-Non-Crystalline-Solids. v 227-230 n Pt 2 May II 1998, p 1345-1348</td>
<td>the 1/f noise does not originate from the structural disorder nor neutral dangling bonds which act as recombination centers, but from the structural non-uniformity causing fluctuations of the carrier conduction.</td>
</tr>
<tr>
<td>54</td>
<td>Dessard-V; Eggemont-JP; Flandre-D</td>
<td>Thin-film SOI n-MOSFET low-frequency noise measurements at elevated temperatures</td>
<td>High-Temperature Electronic Materials, Devices and Sensors Conference (Cat. No.98EX132). IEEE, New York, NY, USA; 1998; xvi+221 pp. p.95-7</td>
<td>1/f noise measurements on thin-film SOI n-MOSFETs up to 250 degrees C using the superiority of thin-film fully-depleted (FD) SOI n-MOSFETs versus partially-depleted (PD) devices from a noise perspective over temperature.</td>
</tr>
<tr>
<td>55</td>
<td>Arora-SK; Kumar-R; Kanjilal-D; Bathe-R; Patil-SI; Ogale-SB; Mehta-GK</td>
<td>1/f noise properties of a La1_xCa_xMnO3 thin film</td>
<td>Solid-State-Communications. vol.108, no.12; 1998; p.959-63</td>
<td>The observed noise arises due to the resistance fluctuations and its magnitude follows a power law of the 1/f form.</td>
</tr>
<tr>
<td>56</td>
<td>Dessard-V; Flandre-D</td>
<td>Low frequency noise measurements at elevated temperatures on thin-film SOI n-MOSFET</td>
<td>ESSDERC'98. Proceedings of the 28th European Solid-State Device Research Conference. Editions Frontieres, Paris, France; 1998; xvi+651 pp. p.604-7</td>
<td>Low-frequency noise measurements on thin-film SOI n-MOSFETs have been performed from room temperature up to 250 degrees C. it is observed the constancy of 1/f noise with temperature while the devices remain fully-depleted whereas a new noise contribution appears under certain conditions. A first-order interpretation is proposed for this additional noise.</td>
</tr>
<tr>
<td>57</td>
<td>Yu-Cheng; Jeng-Gong; Der-Ming-Liou; Hoshin-Yee</td>
<td>The 1/f noise associated with electromigration in AlSiCu thin films</td>
<td>Japanese-Journal-of-Applied-Physics.-Part-I-(Regular-Papers.-Short-Notes-&amp; -Review-Papers). vol.38, no.1A; Jan. 1999; p.291-2</td>
<td>The experimental results showed that single-layer AlSiCu films have 1/f noise only, and no 1/f2 noise is observed during the entire stress period.</td>
</tr>
<tr>
<td>58</td>
<td>Su-YK; Fuh-Shyang-Juang; Shing-Ming-Chang; Cheng-Der-Chiang; Ya-Tung-Cheng</td>
<td>1/f noise and specific detectivity of HgCdTe photodiodes passivated with ZnS-CdS films</td>
<td>IEEE-Journal-of-Quantum-Electronics. vol.35, no.5; May 1999; p.751-6</td>
<td>At low temperatures, where surface generation and leakage current were predominant, a linear relationship between 1/f noise and dark current was observed. At higher temperatures, where diffusion current is predominant, the correlation no longer holds. The temperature dependence of 1/f noise was also determined.</td>
</tr>
<tr>
<td>59</td>
<td>Angelis-CT; Dimitriadis-CA; Brini-J; Kamarinos-G; Gueorguiev-VK; Ivanov-TE</td>
<td>Low-frequency noise spectroscopy of polycrystalline silicon thin-film transistors</td>
<td>IEEE-Transactions-on-Electron-Devices. vol.46, no.5; May 1999; p.968-74</td>
<td>The 1/f noise is explained with an existing model developed for monocrystalline silicon based on fluctuations of the inversion charge near the silicon-oxide interface. The Lorentzian spectrum is explained by fluctuations of the grain boundary interface charge with a model based on a Gaussian distribution of the potential barriers over the grain boundary plane.</td>
</tr>
</tbody>
</table>
| 60 | Chen-XY; Salm-C; Hooge-FN; Woerlee-PH | 1/f noise in polycrystalline SiGe analyzed in terms of mobility fluctuations | Solid-State-Electronics vol.43, no.9; Sept. 1999; p.1715-24 | It is found that the 1/f noise parameter $\alpha$ decreases with increasing mobility, which does not agree with the parameter as measured in crystalline semiconductor material grown by molecular beam epitaxy.

| 61 | Arora-SK; Kumar-R; Singh-R; Kanjilal-D; Mehta-GK; Bathe-R; Patil-SI; Ogale - SB | Electronic transport and 1/f noise studies in 250 MeV $^{107}$Ag ion irradiated La$_{0.75}$Ca$_{0.25}$MnO$_3$ thin films | Journal-of- Applied-Physics vol.86, no.8; 15 Oct. 1999; p.4452-7 | The resistivity of the sample irradiated decreases in the ferromagnetic metallic state compared to that of an unirradiated sample.

| 62 | Xu-Yizi; Ekin-JW; Clickner-CC | Low-frequency noise of YBCO/Au junctions | IEEE-Transactions-on-Applied-Superconductivity v 9 n 2 III 1999, p.3990-3993 | YBCO/Au junctions with low contact resistivities, exhibit large low-frequency resistance fluctuations.

| 63 | Tassis-DH; Dimitriadis-CA; Polychroniadis-EK; Brini-J; Kamarinos-G | Structural and trap properties of polycrystalline semiconducting FeSi$_2$ thin films | Semiconductor-Science-and-Technology v 14 n 11 1999, p 967-974 | The power spectral density of the current fluctuations shows a 1/f prime (with gamma greater than 1) behaviour and is proportional to $i^\beta$ (with $\beta$ less than 2).

| 64 | Arora-SK; Kumar-Ravi; Kanjilal-D; Mehta-GK; Khatua-S; Pinto-R; Kumar-Vijay; Gupta-AK | 1/f noise properties of swift heavy ion irradiated epitaxial thin films of YBCO | Bulletin-of-Materials-Science. v 22 n 3 1999, p 251-255 | The magnitude of $S$, has been found to decrease with decrease in temperature and shows a 1/f noise peak in the transition region.

| 65 | Selders-Peter; Castellanos-Ana-M; Vaupel-Mathias; Woerdnweber-Roger | Reduction of 1/f-noise in HTS-SQUIDs by artificial defects | IEEE-Transactions-on- Applied-Superconductivity v 9 n 2 III 1999, p 2967-2970 | Reports on the detection of matching effects between antidot and vortex lattices in rf SQUIDs that clearly demonstrate, that antidots can strongly reduce the low-frequency 1/f noise in active superconducting devices.

| 66 | Head-LM; Fahrenkrug-C | Voltage transients in electromigration noise measurement data | Microelectronics-and-Reliability. v 39 n 4 1999, p 529-535 | The presence of voltage transients in noise data, caused by abrupt changes of resistance in a thin-film test structure, is shown to be the primary source of 1/f$^2$ noise. |
Table 5.2 Details of the films used for the 1/f Noise Studies

Films grown in present work are of almost same dimensions: 4 cm x 1 cm

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Material Used</th>
<th>Thickness Of the Film in Å Units</th>
<th>Substrate Used to Deposit</th>
<th>Substrate Temperature During Deposition</th>
<th>Vacuum</th>
<th>Rate of Deposition Å s⁻¹</th>
<th>Deposition Method (Thermal evaporation) Using</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Aluminum</td>
<td>400, 600, 800, 1000</td>
<td>Glass</td>
<td>310 K</td>
<td>4X10⁻⁶ mbar</td>
<td>2.4</td>
<td>Resistive heating</td>
</tr>
<tr>
<td>2.</td>
<td>Silver</td>
<td>400, 660, 880, 1100</td>
<td>Glass</td>
<td>310 K</td>
<td>4X10⁻⁶ mbar</td>
<td>2.4</td>
<td>Resistive heating</td>
</tr>
<tr>
<td>3.</td>
<td>Gold</td>
<td>400, 660, 880, 1100</td>
<td>Glass</td>
<td>310 K</td>
<td>4X10⁻⁶ mbar</td>
<td>2.4</td>
<td>Resistive heating</td>
</tr>
<tr>
<td>4.</td>
<td>Cu₂Se</td>
<td>10000,46000,61000 and 85000</td>
<td>Glass</td>
<td>310 K, 360 K, and 410K</td>
<td>2X10⁻⁵ mbar</td>
<td>10</td>
<td>Resistive heating</td>
</tr>
<tr>
<td>5.</td>
<td>Cu₂Se</td>
<td>10000,46000,61000 and 85000</td>
<td>Mica</td>
<td>310 K, 360 K, and 410K</td>
<td>2X10⁻⁵ mbar</td>
<td>10</td>
<td>Resistive heating</td>
</tr>
<tr>
<td>6.</td>
<td>CdSe</td>
<td>6000, 8000, 10000</td>
<td>Glass</td>
<td>310 K</td>
<td>2X10⁻⁵ mbar</td>
<td>10</td>
<td>Resistive heating</td>
</tr>
<tr>
<td>7.</td>
<td>Tellurium</td>
<td>4590, 6620, 10180</td>
<td>Glass</td>
<td>310 K</td>
<td>2X10⁻⁵ mbar</td>
<td>10</td>
<td>Resistive heating</td>
</tr>
<tr>
<td>8.</td>
<td>Tellurium</td>
<td>4590, 6620, 10180</td>
<td>Mica</td>
<td>310 K</td>
<td>2X10⁻⁵ mbar</td>
<td>10</td>
<td>Resistive heating</td>
</tr>
</tbody>
</table>
References of Chapter 5

References 1 to 66 are cited in Table 5.1 in order.


72. Kleinpenning TGM, Solid State Electronics, 22, p121 (1979)


