7.1 Introduction

Studies of the dielectric breakdown properties are of fundamental importance for the systematic development of a wide variety of components in optical and microelectronic devices. There has been a great interest in this study because of the above mentioned applications and also because the phenomenon is yet to be fully understood. Although breakdown in thin films is a simpler phenomenon than in bulk materials, still considerable difficulties are encountered in the theoretical interpretation and experimental verification of this phenomena. Inspite of the extensive work in this field, inconclusive relation exists between the theory and the experimentally observed facts [1]. The criterion that determines breakdown is the instability, which at a crucial field manifests itself in current runaway to infinity or by the onset of a negative differential resistance range in the current-voltage characteristics. As in thermal breakdown, the instability in non-thermal breakdowns is explained by the positive feedback effects.

On going through the different theories proposed, a crucial point is noticed to establish whether the breakdown results from a strictly local event or rather is the consequence of a phenomenon propagating with an increase of intensity. In order to answer this question, experiments have been performed on samples
subjected to pulses of breakdown voltages [2] or on samples based on the pre-breakdown region and illuminated by flashes of light [3] or thorough investigations of pre-breakdown light emission [4]. Many experiments on films have shown the dependence of the dielectric strength upon the film thickness and temperature [5-8]. In recent times, testing methods have been developed by which a number of specimens have been analysed when breakdowns are non-shorting [9-11] and non-destructive [12].

Earlier, breakdown studies have been carried out on semiconductors to understand the mechanism based on the proposed breakdown theories [13-15]. No work has been done on thickness as well as temperature dependence of breakdown properties of \( \text{Sb}_2\text{Se}_3 \) thin films. This chapter represents the breakdown studies performed on \( \text{Sb}_2\text{Se}_3 \) thin films deposited by vacuum evaporation. The observed results are discussed in the light of available theories.

7.2 Theory

In this section the breakdown theories proposed by Forlani and Minnaja [16-17], O'Dwyer [18] and Klein and Gafni [19] have been discussed. The first two are based upon the ideas of electron avalanche developed by Von Hippel [20], Frohlich [21], Seitz [22], Gallen [23] and Franz [24]. The treatment of Klein and Gafni is based upon the thermal breakdown.

7.2.1 Theory of Forlani and Minnaja

Forlani and Minnaja describe the onset of breakdown in an
ionic crystal by considering the injected electrons from the cathode as free electrons in the conduction band of the dielectric. The acceleration of these electrons in a field is impelled by electron-phonon collisions. Electrons with energy larger than the unstable equilibrium energy, gain energy from this field till they attain the ionization energy of the dielectric crystal. The current is then enhanced by ionizing collisions. The thickness dependence of the breakdown field strength ($F_B$) can be obtained from the electron current equation. The field $F_B$ varies as $d^{-\alpha}$ where $d$ is the film thickness and $\alpha$ varies from 0.25 to 0.50. The different exponentials are justified by two mechanisms, namely the tunnel injection of electrons from the cathode and the electron-phonon scattering. Also $F_B$ is independent of thickness comparable to the hole-electron recombination distance. Theories based on the electron-phonon scattering state that the dielectric field strength increases as the temperature increases. A decrease of the dielectric field strength with increasing temperature is obtained provided the electron-electron scattering is taken into account. Experiments have shown that there exists a transition temperature between a breakdown dominated by phonon scattering and a breakdown affected predominately by electron-electron scattering.

7.2.2. Theory of O'Dwyer

The theory of O'Dwyer incorporates a condition of current continuity during avalanche process which causes the field to be
heterogeneous, being considerably larger at the cathode than elsewhere. The breakdown mechanism is associated with impact ionization. The instability is due to the positive feedback between the holes which are trapped by impact ionization and the electrons which are injected from the cathode. The injection is enhanced by trapped holes owing to the increase in field at the cathode. This results in increase in impact ionization and hole trapping. When these risings cannot be balanced by hole drift, current runaway and breakdown follows.

7.2.3. Klein’s theory

The theory proposed by Klein and Gafni is based on a succession of electron avalanche processes due to impact ionization and the injection of electrons into the conduction band when an electric field is applied across the thin film capacitor. An electron produced at the cathode produces an avalanche of free electrons by impact ionization and the positive charges are left behind in the insulator. These positive charges have a very low mobility and hence drift slowly to the cathode forming a positive charge cluster. This results in the enhancement of field at the cathode. The local injection rate of electrons increases and a finite probability is reached for an electron to hit the tiny charge cluster during transit through the insulator. The average cathode field during the transit of the charge cluster increases with film thickness. Hence the formation of large avalanche also depends on the film thickness, in addition to other parameters.
involved.

The breakdown, according to this theory follows in a sequence of stages. In the initial stage harmless avalanche occurs in the whole of the specimen causing the temperature to rise significantly. This enhances the critical conductivity leading to a thermally unstable state at the breakdown spot in the specimen which finally results in voltage collapse through current runaway. Impact ionization may stop during voltage collapse, but the breakdown events continue until destruction occurs because of the thermally unstable state, due to the temperature rise at the site. Thus a complete breakdown event comprises the initiation of breakdown, instability due to heating and finally the destruction of the capacitor with voltage collapse.

7.3 Measurements

Vacuum deposited Sb₂Se₃ thin film capacitors have been fabricated as described in chapter II. During breakdown, destruction of the dielectric occurs by vapourization rather than by melting. Hence for the occurrence of non-shorting breakdown of the MSM structure, one of the electrodes was deposited with low thickness.

Breakdown studies were carried out on Sb₂Se₃ thin films of thickness in the range 95 to 350 nm. A d.c power supply was used in series with the specimen capacitor, a standard 1 kΩ limiting resistor and an electrometer amplifier. For measurement of higher currents a digital multimeter was employed. Application
of the voltage to the capacitor was done in equal incremental steps which was also measured by a digital multimeter. The onset of breakdown in these capacitors was detected by a sudden and sharp current surge at the breakdown voltage. In MSM structure, the phenomenon initiates with slow emanation of light and spreads in the form of a spider pattern. In some cases the breakdown resulted in the complete damage of the top electrodes while the semiconductor and the bottom electrode remain unaffected. The effect of breakdown was observed to be more prominent at the edges. The observed breakdown patterns have been photographed and presented.

7.4 Results and discussion

7.4.1 Thickness and temperature dependence of onset breakdown field

A doubly logarithmic plot of onset breakdown field against film thickness for Sb$_2$Se$_3$ thin films deposited with substrate temperature $T_S = 303$ and 493 K is shown in Fig. 7.1. The breakdown field strength is observed to vary from $1.2 \times 10^8$ V/m to $2.5 \times 10^7$ V/m in the thickness range 95 to 350 nm for amorphous films ($T_S = 303$ K). The breakdown field strength for polycrystalline films ($T_S = 493$ K) is found to vary from $6.02 \times 10^7$ V/m to $1.15 \times 10^7$ V/m in the same thickness range. Although the breakdown strength of a dielectric is an intrinsic property, it is very likely that the microstructure of the films will greatly influence the breakdown strength. The grain boundaries in polycrystal-
Fig 7.1 VARIATION OF ONSET BREAKDOWN FIELD (Fb) WITH THICKNESS OF Sb$_2$Se$_3$ FILMS

- $T_s = 303$ K
- $T_s = 493$ K
line films can act as fast diffusion paths and sites for preferential absorption of impurities, eventually affecting the breakdown strength. In contrast amorphous films are usually insensitive to impurities [25] and whole state owing to the absence of grain boundaries. Thus the amorphous nature of the film is likely to increase the dielectric breakdown strength. In the present study Sb$_2$Se$_3$ films deposited at T$_S$ = 303 and 493K were found to have amorphous and polycrystalline structure respectively as shown in chapter III. Hence the low value of breakdown for polycrystalline films could easily be understood.

The Forlani-Minnaja theory mentioned in section 7.2 predicts a thickness dependence of the form $F_B \propto d^{-\alpha}$ where $\alpha$ varies from 0.25 to 0.50. This theory also predicts that the higher value 0.50 holds good for high energy gap dielectrics. In the present investigation the values obtained being 1.3, the thickness dependence of the breakdown field in both amorphous and polycrystalline Sb$_2$Se$_3$ chalcogenide semiconductor thin films does not obey the Forlani-Minnaja theory which holds good only for dielectrics.

Fig. 7.2 represents the variation of onset breakdown field with temperature (303-583 K) for Sb$_2$Se$_3$ thin films of typical thickness 120 and 190 nm. From the Fig. 7.2 it is observed that the breakdown field decreases with increase of temperature for all the vacuum deposited Sb$_2$Se$_3$ films.
Fig 7.2 VARIATION OF ONSET BREAKDOWN FIELD ($F_b$) WITH TEMPERATURE OF Sb$_2$Se$_3$ FILMS
7.4.2. Breakdown Patterns

The observed breakdown patterns of Sb$_2$Se$_3$ films photographed under transmitted light are shown in Figs. 7.3 to 7.5. Three types of breakdown found to occur are classified according to the mode of destruction. This classification is in line with that stated by Klein et al [11]. According to their classification, three types of breakdown are single hole, propagating and maximum voltage breakdown. The first two are attributed to the localised flaws in the films, destroying a small area (hole type) and a large area (propagating type) of the material. The maximum breakdown is considered as a characteristic of the ultimate breakdown strength of the bulk material.

The single hole type breakdown originates from the cathode due to electronic impact ionization and terminates at the anode due to successive avalanches in the same spot thereby enhancing the local temperature. Due to low thermal conductivity of the material, the thermal energy is not dissipated to the surrounding areas and hence results in a rise of temperature and damage to the material. The propagating type of breakdown occurs mostly in amorphous films, since crystalline or partially crystalline films are prone to give directional breakdown. Once breakdown is initiated at a point, it damages and weakens the neighbouring area and another breakdown occurs. Thus the chain continues and breakdown propagates further.
Fig 7.3 (a) SINGLE HOLE TYPE BREAK DOWN PATTERN OF Sb$_2$Se$_3$ THIN FILM (x675)

Fig 7.3 (b) CLUSTER OF SINGLE HOLES OF Sb$_2$Se$_3$ THIN FILM DURING BREAKDOWN
Fig 7.4 (a) PROPAGATING TYPE OF BREAKDOWN PATTERN OF Sb$_2$Se$_3$ THIN FILM UNDER REFLECTED LIGHT (x675)

Fig 7.4 (b) PROPAGATING TYPE OF BREAKDOWN PATTERN OF Sb$_2$Se$_3$ THIN FILM UNDER TRANSMITTED LIGHT (x675)
Fig 7.5 (a) COMPLETE BREAKDOWN SITES OF $\text{Sb}_2\text{Se}_3$ THIN FILM UNDER REFLECTED LIGHT (x675)

Fig 7.5 (b) COMPLETE BREAKDOWN SITES OF $\text{Sb}_2\text{Se}_3$ THIN FILM UNDER TRANSMITTED LIGHT (x675)
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