7.1 **Summary**

In this dissertation various physical phenomena due to hot carrier transport processes in semiconductor devices are presented. The study deals with MOS devices particularly.

The device under study is designed using CAD methods and a set of six levels of mask is made for fabrication of the device. By using the standard experimental techniques for n-channel devices, the MOS transistor is fabricated. Initially all the processing techniques are standardized to get optimum reproducible results. All the experimental parameters obtained from the characteristics of the MOSFET agree with theoretically designed values. The dismounting and wire bonding of the device could be resulted in encapsulated device suitable for carrying out various measurements. It is believed, the process followed in fabricating the device yielded the best possible device performance applicable for MOS integrated circuits.

Among the various physical phenomena of the hot carriers, the photon emission due to carrier generation and recombination is an important one. In MOS devices till recent years the study of hot carrier effects was mainly concerned with substrate and gate current measurement and the resulting trapping in the SiO₂.
We extend the observation of various hot carrier induced phenomena by measuring the intensity of light emission from the MOSFET and its variation with the different modes of device operation. Photon generation occurs in forward as well as reverse biased Si junctions. In MOSFETs the photons produce electron hole pairs in and near the drain depletion region which greatly change the characteristics of the device such as holding and refreshing time in MOS memories. This has serious effects in VLSI chips and so requires a detailed study. In view of the above reasons, we have studied and presented the various mechanisms of photon emission and its relation with substrate and gate current of the device.

A theoretical model is presented for the avalanche drain current which is believed to be a measure of the light emission. The approximations used for the derivation have taken into account the actual device operational conditions and thus, both theoretical calculations and experimental results agree with each other within the limit of the experimental procedure.

The study is carried out on both the enhancement mode and depletion mode transistors. Three different types of devices have been fabricated by varying the implantation dose but with same energy of implantation. Unlike the enhancement mode transistors, in this case there is no light emission from the drain-gate boundary. The conducting channel is at a certain depth below the Si-$\text{SiO}_2$ interface and hence the photons.
generated at the junction are lost while reaching the Si surface. Optical photographs of light emission are taken for visual record of the light emission by using high speed polaroid film. The field distribution of the drain-substrate depletion region depends on the implantation dose in addition to the drain bias values. Gate current in the depletion mode transistor changes its polarity with gate voltage which is not observed in the case of enhancement mode transistors. From all these observations it is concluded that light emission measurement has proved to be an important tool to study the high field effects in MOS transistors.

The study concerning infrared emission due to the excitation of 2-D inversion layer plasmon, by hot electrons moving from the source to the drain, is made in detail. In chapter V, the plasma oscillations of nonradiative type are discussed. The theoretical solution for the radiative type is presented in the later chapter. Coupling of the inversion layer plasmon and gate electrode plasmon due to a very thin layer of SiO$_2$ is studied. The effect of insulator thickness on 2-D plasma frequency is considered. The lifetime of the radiative type oscillations which give the time by which plasmons can decay into single particle is discussed. An experimental study is also made on FTIR spectrometer for the determination of 2-D plasma frequency and its variation with gate bias. Experimental results are compared with theoretically calculated values.
7.2 Concluding Remarks

The design and fabrication of a 500 μ long n-channel metal gate MOSFET is made successfully. It is believed that the standardized procedure followed in fabricating the device has yielded the best possible results. The grating structure in the uppermost gold layer of MOSFET is made to observe the infrared as well as visible light emission from the gate area. The experimentally obtained device parameters agree with theoretically designed values. Visible light emission is observed for the first time to be emitted from Si-MOSFETs. This emission occurs due to the radiative recombination of hot electrons and holes in the device. The variation of light intensity and position of light emission with respect to the gate bias have been measured. The study compares the light intensity with substrate current variation with gate bias of SOS transistor. Though the origin of occurrence of the above parameters is the same i.e. due to hot electron-hole pair generation and recombination in the reverse-biased drain junction, the magnitude as well as peak position vary with respect to the gate bias for each of them. It is concluded that for a detailed understanding of the high field carrier distribution in the MOSFET, the measurement of light intensity is useful.

Hot carrier effects have been studied also for depletion mode transistors. In this case, unlike enhancement mode transistors, the gate current flows due to the transport of holes through the insulator. With an increase of gate bias, the polarity of gate current changes as the electrons start to
flow through the SiO₂. The peak in the gate current varies with the channel dose as the presence of donor impurities changes the threshold voltage in negative direction. Hence the maximum lateral field for avalanche mechanism has different values. The higher the channel doping, lower is the gate current.

The theory of the 2-D plasmon oscillations in the inversion layer of a MOSFET is presented. From the coupling of the inversion layer plasmon with the gate electrode plasmon, it is concluded that an increase of the 2-D plasma frequency has effects similar to a decrease of insulator thickness. From the life time consideration of radiative type plasmon, it is seen that for low values of insulator thickness, the plasmons have a higher life time. Due to the image charges of the gate electrode, screening effects of the plasmon become pronounced. Hence radiative plasmon can have higher life time before decaying into single particle excitations.

Fourier transform infrared spectral study has been made by using a large area MOS capacitor with a grating structure on the gate. Transmittivity of the infrared light is measured over a frequency range for various values of the gate voltage. With an increase of the gate voltage, the peak position of the transmitted signal shifts towards a higher wave number which confirms the theoretical results.

7.3 Scope for Future Work

The results of our experiment show that light intensity measurement is an useful tool for the study of high field
transport phenomena in MOS discrete devices as well as integrated circuits. The photon generation process in the drain depletion region of MOSFET occurs in the bulk of the semiconductor. Our observation is concerned with the number of photons emitted from the device. But some of the photons which are observed in the substrate may create electron-hole pairs. This may give excess current at the source substrate junction, which can make the junction forward biased due to the voltage drop in the substrate. The increase in drain current due to the increase of source current by this process requires a detailed study.

Since the photomultiplier tube used in the present experimental observation has spectral response of 300-650 nm, the infrared emission from the device could not be detected. The study using a PMT with extended range will give details of emission spectra.

The study concerning the variation of the spectral distribution with gate bias will be another interesting investigation. The field distribution due to minority carrier injection may change the energy distribution of the photoemission.

The present study has been made on long channel devices. This may also be studied in short channel devices since here the electric field may be quite high even for low biasing value.
In the calculation of the 2-D plasmon dispersion relation, the carrier density is assumed to be homogeneous in the inversion layer. Spatial variation of carrier density may be more realistic. In the case of the radiative type wave solution, the solution for the plasmon resonance frequency for different insulator thickness will give the exact resonance frequency of the device.

The experimental verification of gate bias dependence of IR transmission spectra over insulator thickness will complete the detailed study of the theoretical results. The study of the grating structure specially transmittance properties in the infrared range will be quite rewarding.