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A Conductance Technique for the Determination of Dopant Characteristics

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When semiconductor devices are operated at very low temperatures, the dopant atoms do not readily get ionized due to freeze-out effects. This causes a delay in the formation of the depletion region when the applied voltage is changed. This manifests itself as a transient in the drain current in MOS devices and a dispersion in CV curves in both field-effect and junction devices. In this paper, we report studies on dispersion effects in CV curves obtained on MOS transistors and p-n junction devices. The device behavior is modeled by an appropriate equivalent circuit. From the measured impedance of the device the conductance is obtained as a function of temperature and frequency. This enables the determination of emission time constant and the capture cross-section of the dopant atoms.

Impedance measurements were carried out on n-channel MOS transistors and p-n junction devices fabricated in a modern CMOS processing facility. The devices were mounted in a cold tip of a helium dewar whose temperature can be set to the desired value any where between room temperature and liquid helium temperature. Figure 1 gives the measured CV curves at different frequencies for the MOS transistor maintained at a temperature of 39 K. Similarly the dispersion observed in th p-n junction device at 36.8 K is shown in Figure 2. The long emission time constant of the dopant atoms causes a dispersion in the CV curves in both cases. The effect of the long emission time constant is modeled by the equivalent circuit shown in Figure 3 for the MOS device. The equivalent circuit for the p-n junction is similar except that the oxide capacitance is excluded. The measured impedance can be represented by a conductance G_p and a capacitance C.

The conductance was determined as a function of frequency and temperature. When the measured G_p/ω is plotted as a function of ω, a peak is observed at a value of ω equal to the reciprocal of the emission time constant. This is shown in Figure 4 for the MOS device and a similar behavior is obtained for the p-n junction although not shown here. In Figures 5 and 6, the reciprocal of the emission time constant is plotted as a function of the reciprocal temperature for the two devices. From the slope of the Arrhenius plot, the energy level of the dopant atoms and the capture cross-section are obtained. For the n-channel MOS transistor we obtain an energy of 39.5 meV and a capture cross-section of $7.68 \times 10^{-15}\ cm^2$ for the acceptor atoms. Considering the p-n junction as an approximate one-sided junction we obtain corresponding values of 39.9 meV and $1.4 \times 10^{-14}\ cm^2$ for the donor atoms. To conclude, it is shown in this study that the conductance technique at very low temperatures is a suitable technique for determining the emission time constant and the capture cross-section of the dopant atoms.

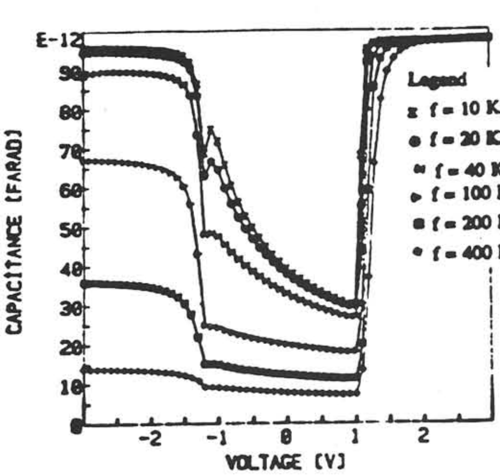

FIG. 1 C-V curves in a NMOS device at 39K

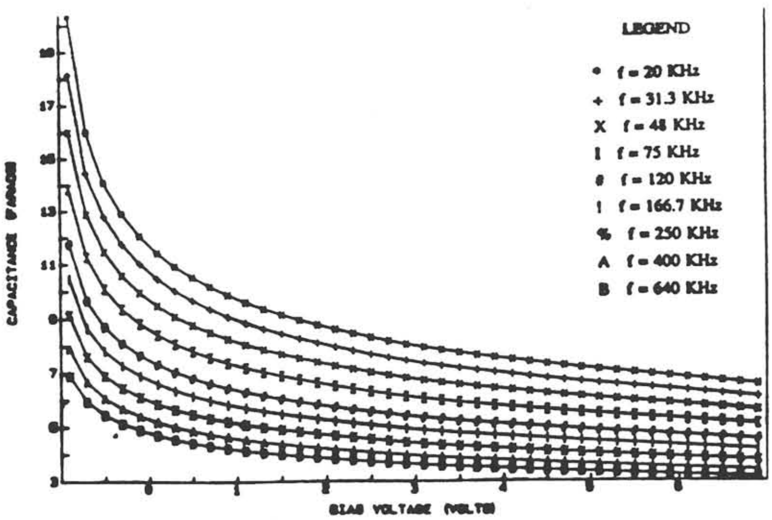

FIG. 2 C-V curves in a diode at 36.8 K

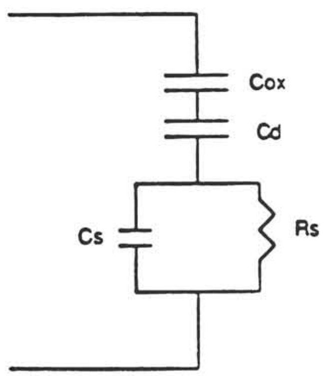

FIG. 3. EQUIVALENT CIRCUIT

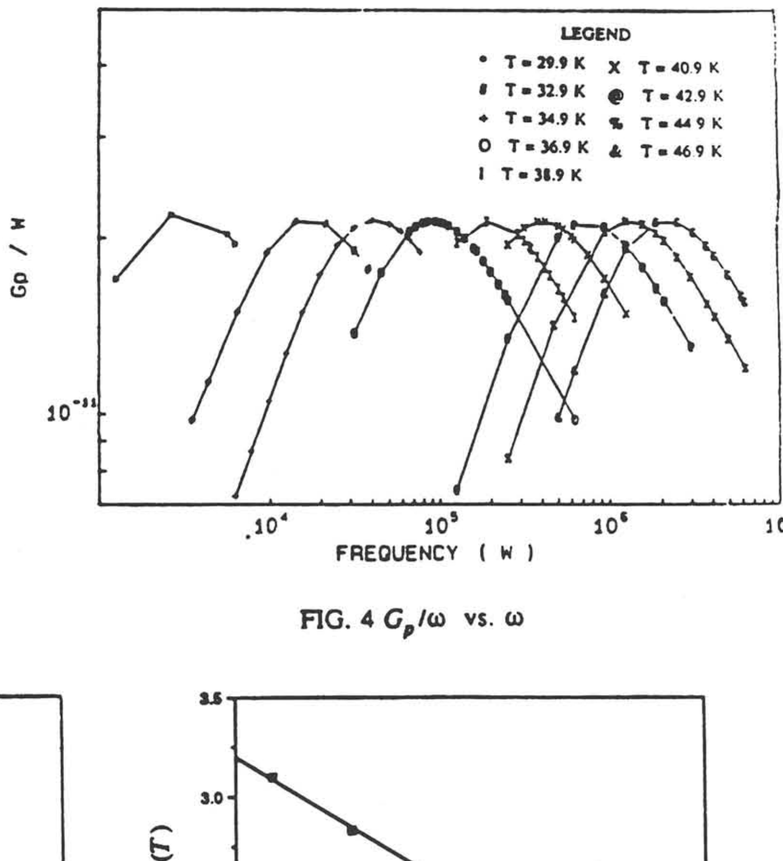

FIG. 4 G_p/ω vs. ω

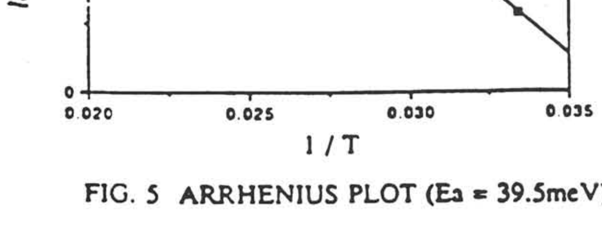

FIG. 5 ARRHENIUS PLOT (Ea = 39.5meV)

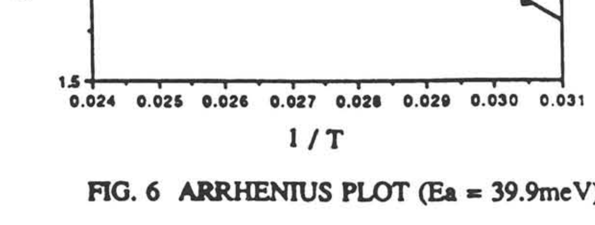

FIG. 6 ARRHENIUS PLOT (Ea = 39.9meV)