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Si:As System Near the Metal - Insulator Transition: Equilibrium and Transport Properties.

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The tendency toward the use of silicon electron devices in the low temperature regime (down to $T = 4.2$ K) has made it almost mandatory the characterization of equilibrium and transport properties of doped silicon in this temperature regime, and the study of these properties is particularly interesting in the concentration range where a semiconductor-to-metal transition is known to occur.

Combined resistivity and Hall mobility technique has been used in the temperature range $10 - 300$ K for ion implanted Si:As samples in the concentration range $10^{18} - 10^{20}$ cm^{-3}. The samples were obtained by ion implantation and subsequent annealing at moderate temperature to obtain a sufficiently flat profile, complete dopant activation, and complete lattice reconstruction. Starting material was p-type, Czochralski grown silicon, boron-doped at an atomic concentration of 5×10^{14} cm^{-3}. This concentration allows us to ignore compensation effects. Dopant distribution, complete activation and recovery of radiation damage were studied by room temperature differential resistivity and Hall mobility profiling. The calculated electrically active amount per unit area at 300 K for concentration below $3\times10^{18} cm^{-3}$ coincide (to within 20%) with the implanted fluence and phenomena due to an incomplete dopant activation are to exclude.

Sheet resistance, R_s , and Hall coefficient, R_{Hs}, measurements were carried out in thermal equilibrium conditions and steady-state currents in a variable cold-end-system. The Hall coefficient was calculated from the slope of the Hall voltage curve vs the magnetic field strength.

Experimental data can be summarized in two families of curves $R_s = R_s(\Phi, T)$ and $R_{Hs} = R_{Hs}(\Phi, T)$ which are integral quantities over the junction depth x_j. In principle we should therefore take into account the depth dependence of carrier concentration and mobility. However, owing to the relative flatness of the dopant profiles we have introduced the approximation of a uniform dopant concentration, $N_D = \Phi/x_b$, over an equivalent depth $x_b < x_j$. This box approximation, in particular with $x_b = 0.7\ x_j$, appears to be acceptable comparing our data $\rho(N_D)$ at 300 K with the literature curve relative to homogeneous samples[1]. In addition, the ionized fraction, $f = 1/e\ R_{Hs}\ \Phi$, measured for low fluence samples ($N_D < 4 \times 10^{18}$ cm^{-3}) can be fitted as a function of temperature, by assuming the standard formula for donor atoms with a single energy level and for quasi-degeneracy conditions[2].

Resistivity and Hall mobility data can be interpreted by a three-band model. According to this model in the lowest band carriers are localized around the dopants, while the intermediate (impurity) and upper (conduction) bands are characterized by a non-null mobility. The energy separations between the lower band and each of the others decrease with N_D. In our case the separation between lower and impurity band vanishes for $N_D \geq 7 \times 10^{18}$ cm^{-3}. This concentration agrees with the value (7.8×10^{18} cm^{-3}) reported by Newman and Holcomb[3] as representative of the metal-insulator transition in Si:As. About the same value for N_D can be obtained by using the Mott's general criterion.

More in detail, the following result follow from our analysis: (*i*) In the semiconductor regime the mobility is described by considering scattering against phonons and ionized and neutral impurities, provided that the decrease of E_C with N_D is considered (*ii*) For high dopant concentration ($N_D \geq 2 \times 10^{19}$ cm^{-3}), μ decreases with T and the sample can be seen as a highly impure Bloch metal.

References

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