S-Shaped Negative Differential Conductance in Semiconductors

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Applying the theory of space charge limited currents (SCLC), we used a FORTRAN code to numerically produced current-voltage characteristic curves for a solid containing traps and donors which exhibit S-shaped Negative Differential Conductance (SNDC) at room temperature. We show that SNDC can arise from doubly occupied traps that are nearly degenerate with the bottom of the conduction band. If the Coulomb energy of two electrons occupying the same trap is such that $E_t + \mathrm{U} \cong 0$ (the zero energy corresponding to the bottom of the conduction band), then the state consisting of two electrons occupying the same trap is degenerate with a singly occupied trap. Using degenerate state perturbation theory, for a two electron system with a single trap and N conduction states, the ground state energy is then given by $2E_t + U - t\sqrt{2N}$, where t is the hopping parameter between trap orbital and conduction band states. Initially, when carriers are injected into the solid, traps begin to fill while the conduction band states stay relatively empty and thus accessible to trapped electrons via hopping. Trap and conduction states continue to be filled as current is increased, and the energy of trapped electrons begins to rise. In some cases, a critical current is reached where upon a further increase in current leads to a reduction of filled traps (i.e. a reduction of space charge in the solid), and thus a corresponding decrease in voltage. This trend in the current-voltage characteristic curves persists until the bottom of the conduction band has been filled, and thereafter voltage rises with current.