POSSIBILITY OF USING INDIRECT TRANSITIONS TO OBTAIN NEGATIVE TEMPERATURES IN SEMICONDUCTORS

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IN some semiconductors, particularly germanium and silicon, the edge of the infrared absorption and emission band corresponds to "indirect" transitions, i.e., processes in which the emission and absorption of a photon is accompanied by simultaneous emission and absorption of a phonon[1-3] This is due to the structure of the bands and takes place when the extrema of the energy with respect to the quasi-momentum of the carriers in the conduction and valence bands correspond to different values of quasimomentum.[4-5]

The radiation of longest wavelength will correspond in such transitions to simultaneous emission of a photon and one phonon (multi-phonon processes can be disregarded as having low probability compared with single-phonon processes). The inverse of the aforementioned process is the simultaneous absorption of a photon and a phonon. Therefore if a sample is at a sufficiently low temperature, when the lattice has practically none of the phonons needed for absorption, radiation of longer wavelength will not be absorbed, and the sample will be practically transparent to such radiation.

If some mechanism (optical illumination, external electric field, etc) increases the concentration of carriers above their equilibrium value, then a negative temperature can be produced relative to the transition under consideration. Estimates show that to produce a negative temperature it is necessary to satisfy the inequality $\omega_r/\omega_f < T_{eff}/T$, where ω_r and ω_f are the photon and phonon frequencies, T the sample temperature, and T_{eff} the effective temperature that determines the filling of the conduction-band levels relative to the valence-band levels. For example, in germanium $\omega_r/\omega_f \sim 25$, i.e., $T_{eff}/T > 25$, which is apparently feasible in the case of a sample cooled to helium temperatures, if the excitation is produced by presently-available radiation sources or an external electric field. However, in order for amplification of radiation to take place in such a system, it is necessary that the induced photon emission prevail over the various absorption processes in the semiconductor (absorption on free carriers, on impurities, etc).[6]

We note that there exists another possibility of producing negative-temperature states in semiconductors. In several papers,[7-10] the observed spectra of recombination radiation of some semiconductors were interpreted as simultaneous emission of a photon and a phonon from exciton states. The mechanism for production of negative temperatures, described above, is fully applicable to such states, too.

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