CONCERNING THE MAXIMUM ENERGY YIELD OF INJECTION ELECTROLUMINESCENCE

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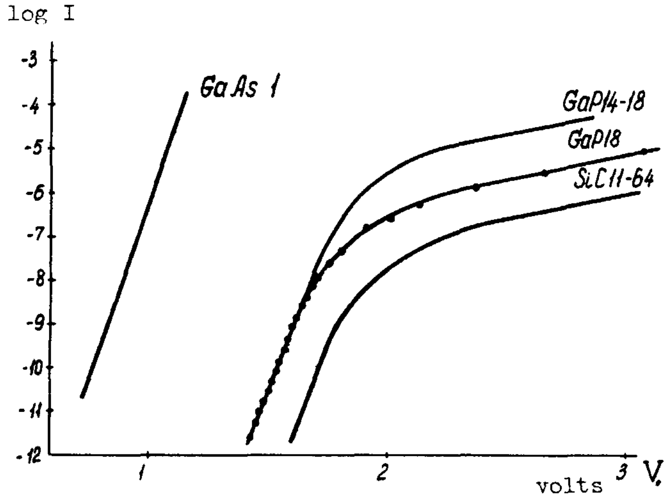
As a result of an analysis of different electroluminescence mechanisms, M. V. Fock [1] concluded that the injection of minority carriers can provide an energy yield many times larger than obtainable with powdered phosphors. A study of this paper may yield the impression that in useful practical cases the energy yield of injection electroluminors may be close to the thermodynamic limit, imposed by the Joule loss in the base material of the apparatus. This point deserves a more thorough examination, since the question of the energy yield is crucial for the use of semiconductors for illumination purposes [2].

We have used injection electroluminesce of diffusion p-n junctions in silicon carbide and in gallium phosphide and arsenide. The samples were prepared by diffusion of acceptors in n-type single crystals with donor density ≈ 1×10^{18} cm^{-3}. The crystals were parallelepipeds with 1 x 1 mm base and 0.3 mm height. The junction plane was parallel to the base. Metallic electrodes deposited on the upper and lower faces provided nonrectifying contacts. The recombination radiation emerged through the side faces. The average acceptor density gradient in the p-n junction region, determined from the voltage dependence of the junction capacitance, was 4×10^{22} cm^{-4}.

We measured the emission spectra, the quantum yield, and the voltage dependence of the recombiantion-radiation intensity in the temperature range from 78 to 400°K. The maximum current density, which depended on the heat rise of the sample, was 1 A/cm^2.

The figure shows typical lumen-voltage characteristics of several junctions, obtained at room temperature. The experimental results are marked on one of the curves.



Recombination radiation intensity vs. voltage applied to p-n junction

When the electroluminors were weakly excited, the recombination-radiation intensity (B) had the following variation with the applied voltage (U) and the temperature (T):

$$B = B_0|T| \exp(eU/kT),$$

where $B_0(T)$ is a coefficient that depends on T but not on U, e is the electron charge, and k is Boltzmann's constant. The form of the argument of the exponential in this formula indicates that the electrons participating in the radiative recombination have Boltzmann statistics and consequently overcome the potential barrier at the expense of the thermal energy. At room temperature the numerical values of the energies of the quanta (in electron volts) at the maxima of the emission spectra exceeded the minimum applied voltages (in volts) at which glow became noticeable by 0.7, 0.33, and 0.25 V for GaAs, GaP, and SiC, respectively. Consequently the carriers participating in the radiative recombination drew 10 - 50% of the radiated energy from the heat stored in the lattice.

If there is no external extinction in the radiative-recombination centers and they are isolated from the extinction centers, then these values correspond to a definite gain in the energy yield for the given electroluminor. The results are close to the maximum electroluminescence energy gain allowed from the thermodynamic point of view [3].

In the GaAs samples the Joule loss was small in the entire investigated range, up to currents that cause heating of the samples. In the case of strongly excited GaP and SiC p-n junctions, deviation of the lumen-voltage characteristics from exponential was observed, caused by the Joule loss in the high-resistance layer formed in the diffusion p-n junction as a result of impurity compensation [4,5]. This loss can be greatly reduced by decreasing the layer thickness.

Calculation shows that the resistance of the base material of all the investigated p-n junctions is so small, that the Joule loss in it is appreciably smaller than the energy loss connected with the nonradiative recombination. The latter heats the samples and thereby prevents further increase of the electroluminescence brightness.

At room temperature the maximum external quantum yield of the samples investigated by us reached 0.7%, 0.02%, and 0.1% for GaAs, GaP, and SiC, respectively. The internal quantum yield was at least one order of magnitude higher. If there is no internal extinction in the luminescence centers of these materials, then light sources with an energy yield close to the thermodynamic limit can be produced by purifying the semiconductors from the luminescence quenchers, since the Joule loss is sufficiently small in a wide range of currents. However, the production of low-resistance luminors with near-unity quantum yield presents certain technological difficulties.

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