PHONON-ASSISTED AND PHONON-FREE RADIATIVE TRANSITIONS IN SULFUR-DOPED GaAs DIFFUSED JUNCTIONS

R. C. C. Leite,[1] J. C. Sarace, and A. Yariv[2]
Bell Telephone Laboratories, Inc., Murray Hill, New Jersey
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In the course of electroluminescence studies of GaAs junctions we investigated the emission spectra of sulfur-doped zinc-diffused diodes. The peaks in the spectra correspond to three main transitions and their associated phonon emission satellites.

The diodes were obtained by a diffusion of Zn from a surface concentration of 5.0×10^{18} cm^{-3} into a sulfur-doped crystal with an electron concentration of 2.0×10^{16} cm^{-3}. The net impurity profile was shown by capacitance measurements to be abrupt with a zero-bias width of 3340 Å at 300°K. The areas of the junctions were $\sim 10^{-3}$ cm^2.

The diode series resistance decreased with an increase in temperature, from 12 Ω at 4.2°K, 6 Ω at 20°K and to 1.7 Ω at 77°K, a behavior possibly due to impurity band conduction at low temperatures in the *p*-type side of the diode.

The average external efficiency at 4.2°K, estimated from the measured external efficiency at 77°K and the ratio of the integrated spectral intensities at the two temperatures, was 30%. The external efficiencies at 77°K varied from 0.4 to 0.8% and were measured with a silicon solar cell whose detection efficiency was assumed to be 0.5. Figure 1 shows the variation of external efficiency with current at 4.2°K for a diode whose ratio of integrated intensities was 80. The maximum value of 30% suggests the plausibility of a quantum efficiency equal to unity in the high current region.

The most intense emission peak shifts with applied voltage. A plot of integrated light intensity vs photon energy of the peak (Fig. 2) at 4.2 and 20°K displays two regions. In region *A*, $h\nu < 1.48$ eV,

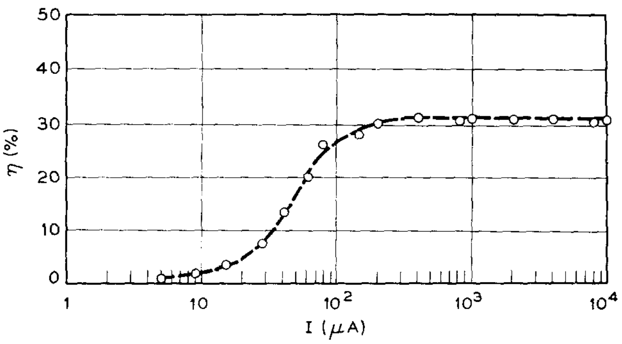

Fig. 1. Variation of external efficiency with current.

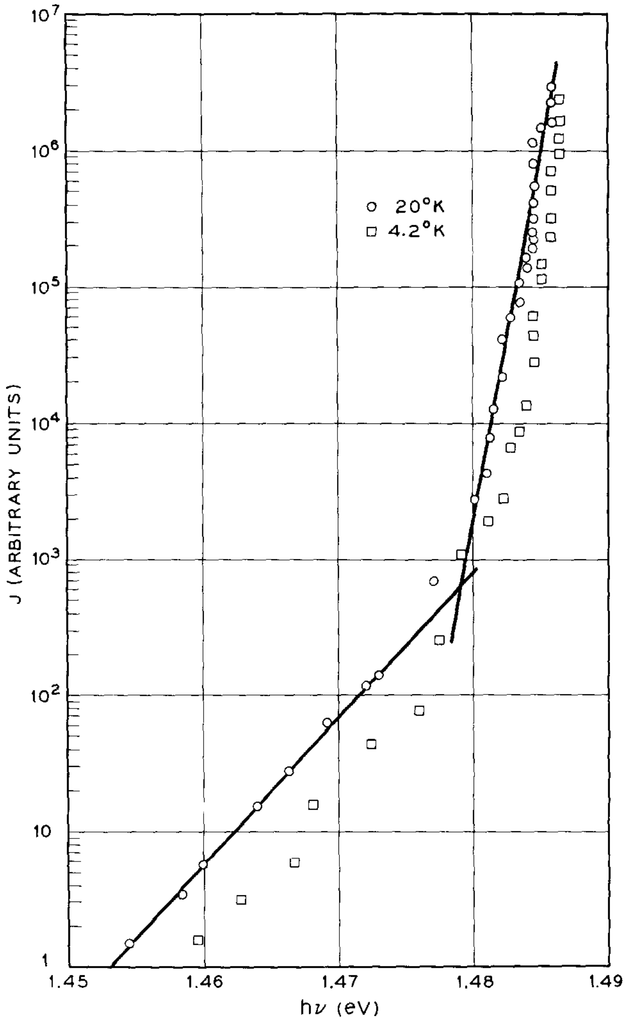

Fig. 2. Plot of the integrated light intensity vs photon energy at 4.2 and 20°K, for the main emission (ν_1 in Fig. 3).

the intensity is given by $J = J_0 \exp[S_A h\nu]$ where $S_A = 247$ (eV)$^{-1}$. In region *B*, $h\nu > 1.48$ eV the slope changes to $S_B \approx 1400$ (eV)$^{-1}$. S_B remains constant up to 77°K, suggesting a tunneling mechanism.[3] Because of the decrease of quantum efficiency at 77°K, it was impossible to obtain data in region *A* at this temperature.

Figure 3*A* and 3*B* shows the electroluminescence spectra at 4.2°K and 77°K for a characteristic current of 25 mA. The lesser peaks shift with applied voltage in the same manner as the most intense peak. The spectrum at 20°K is the same as the one at 4.2°K, except for being displaced to lower energies by 2.5 meV as can be noted from Fig. 2. A peak at 1.486 eV is seen at very low currents (Fig. 3C). Below 15 μA it is the only emission present; at this point the main peak appears and the 1.486-eV peak, which grows superlinearly with current, saturates drastically at 20 μA. With further increase of the current the main peak shifts toward higher energies and the 1.486-eV peak is then masked completely; its energy does not shift with current, before or after saturation. It is quite similar to one which appears at low current densities. in Te-doped junctions[4] and saturates in the same fashion at somewhat higher current densities. This suggests that the transition does not involve sulfur atoms, but some residual impurity; its energy and saturation suggest a bound exciton annihilation, but further work remains to be done.

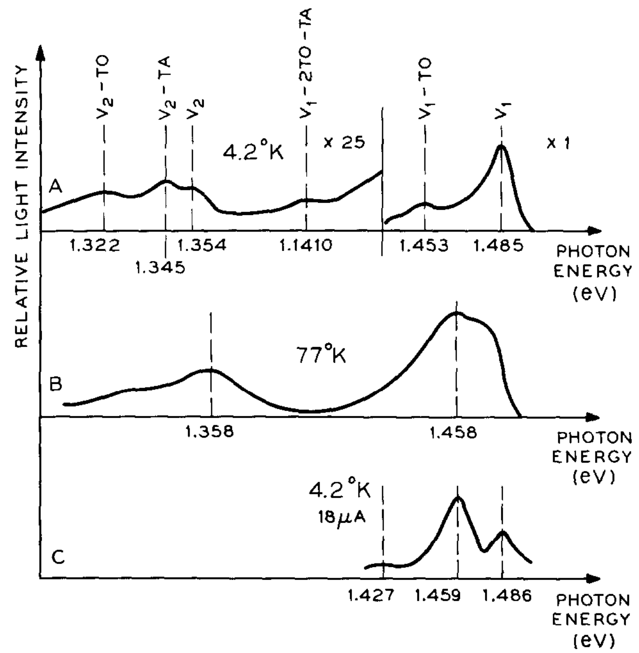

Fig. 3. Electroluminescence spectra at 4.2 and 77°K. *A* and *B*, 25 mA characteristic current; *C*, 18 μA.

The rest of the spectrum at 4.2°K (Fig. 3*A*) consists of two main transitions; ν_1 at 1.485 eV and ν_2 at 1.354 eV. The remaining peaks can be explained as phonon satellites involving the emission of transverse optical (TO) phonons of 32-meV energy and of transverse acoustic (TA) phonons of ~9 meV as shown in Fig. 3*A*. The TO phonons have been reported by Cochran and others[5] and Spitzer.[6] The energy of the TA phonon has been uncertain; Cochran and others inferred a value of 9 to 8 meV from phonon combination bands while Spitzer explained the same data by a different phonon assignment where the lowest energy phonon is TA of 15.7 meV. Our direct observation of the 9-meV TA phonon lends support to the five phonon assignments of Cochran and others. As the spectrum in Fig. 3*A* was not seen in Te-doped diodes,[4] one is tempted to relate those lines to transitions involving sulfur atoms, the two main emissions ν_1 and ν_2 concerning sulfur atoms in different lattice positions. The second line ν_2, which shifts with applied voltage, might also be due to an extraneous impurity in the S-doped diodes. The observation that the main emission occurs at a frequency lower than the 1.486-eV impurity line suggests that the strongest peak is not due to band-to-band transitions. The same is true for diodes with Te concentrations up to 5×10^{17} cm^{-3} where the 1.486-eV peak was observed at low currents.

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[1]On leave of absence from the Instituto Technologico de Aeronautica, Brazil.

[2]Present address: Watkins-Johnson Company, Palo Alto, California.

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