SEMICONDUCTOR MASER OF GaAs

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SEMICONDUCTOR MASER OF GaAs

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The possibility of achieving maser operation in semiconductors has been considered theoretically by several workers.[1-3] It appeared likely that all the requirements for a maser could be fulfilled by the recently developed GaAs diffused diodes, which convert electrical energy to narrow-line infrared radiation with extremely high efficiency.[4] In fact, Hall and coworkers[5] have just reported having obtained coherent radiation from such diodes in pulsed operation at 77°K.[6] Working along independent lines, we have also obtained coherent radiation from GaAs diodes at 77°K and greatly improved performance at 4.2°K.

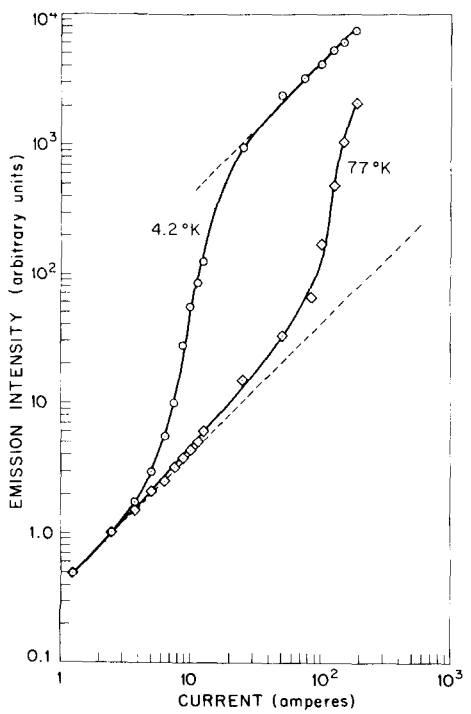

Fig. 1. Light emission from polished surface of GaAs diode as a function of current at 77°K and 4.2°K.

Our results were obtained with diodes which had a line mesa structure with junction area 1.4 × 0.6 mm, the short sides being polished optically flat and nearly parallel. Current pulses of up to 190 A were applied to the diode. At 77°K the radiation was emitted in the usual fashion until the current reached a threshold value of about 90 A, approximately 10^4 A/cm^2, above which the light radiated from the end increased drastically as shown in Fig. 1. At 4.2°K, as shown in Fig. 1, the threshold was lowered by a factor of 15 to approximately 6 A or about 700 A/cm^2. Well above threshold the light output again became linear with current. The spectrum of the infrared emission at 77°K above and below the threshold are shown in Fig. 2*a*. The curves were taken with essentially the same average output at the peak wavelength, the spectral response of the incoherent mode being obtained on a continuous basis and that of the coherent mode with 5 μsec pulses at a 13-cps repetition rate. The spectrum at 77°K showed multiple peaks of approximately 10-Å separation. As can be seen in Fig. 2*a*, the line has narrowed from approximately 175 Å to about 30 Å. At 4.2°K, as shown in Fig. 2*b*, the emitted line narrowed still further from about 100 Å to less than 5 Å. This strong narrowing obviously suggests maser action or coherence. At higher power levels the line broadened and showed structure, presumably due to the excitation of additional modes. To further confirm this conclusion that the diode was masering, we made two other observations. We looked at the diode output through a "snooperscope" and above the threshold observed a very intense and narrow beam radiating from the junction region in the horizontal plane of the junction with a vertical half-power beamwidth of less than 10°. Another observation was made with the use of Polaroid sheets to study the polarization of the beam. Below threshold the light was unpolarized; above threshold the electric vector was predominantly in the plane of the junction.

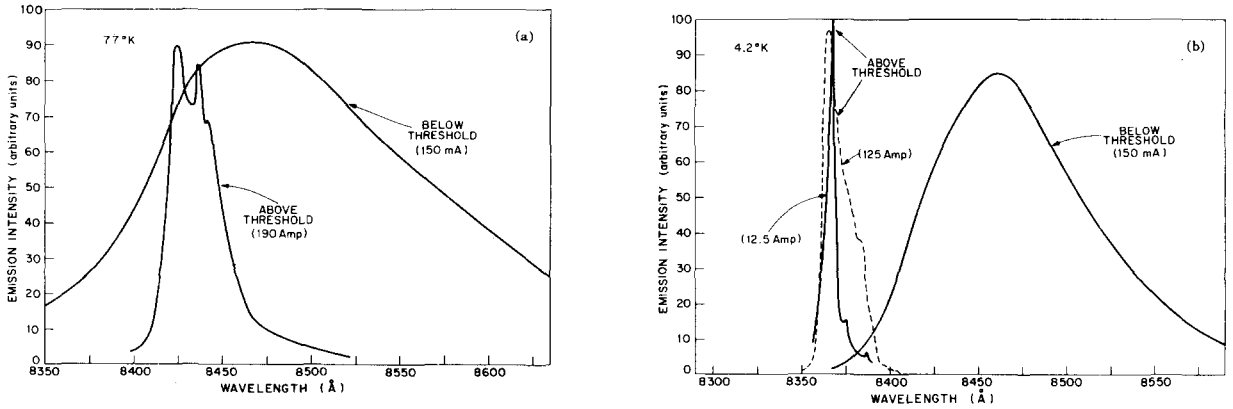

Fig. 2. Spectrum of emitted radiation before and after threshold, both for 77°K (*a*) and 4.2°K (*b*). The resolution of grating spectrometer is 4 Å. The emission intensity scale is different from curve to curve.

We believe that at 4.2°K in the linear region well above threshold, the maser is operating at nearly unity quantum efficiency, *i.e.*, that for every electron crossing the junction, nearly one photon is emitted. A full confirmation will require an absolute measurement of the light output. If, in fact, the diode has unity quantum efficiency, then at our present maximum current of 190 A the peak radiated power is about 280 W (ref 7).

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[1]H. J. Zeiger, *Quarterly Progress Report on Solid State Research, Lincoln Laboratory, M.I.T.* (15 October 1959), pp 41–43, AD231991.

[2]M. G. Bernard and G. Duraffourg, *Physica Status Solida* **1**, 699 (1961).

[3]W. P. Dumke, *Phys. Rev.* **127**, 1559 (1962).

[4]R. J. Keyes and T. M. Quist, *Proc. IRE* **50**, 1822 (1962).

[5]R. N. Hall, G. E. Fenner, J. D. Kingsley, T. J. Soltys, and R. O. Carlson, *Phys. Rev. Letters* (to be published).

[6]Note added after submission: We have just become aware that maser action has also been achieved in GaAs diodes at 77°K by M. I. Nathan, W. P. Dumke, G. Burns, F. H. Dill, and G. J. Lasher, *Appl. Phys. Letters* **1**, 62 (1962).

[7]Note added after submission: This has now been confirmed by an absolute measurement.