Applied Physics Letters

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Cite as: Appl. Phys. Lett. **1**, 62 (1962); https://doi.org/10.1063/1.1777371
Submitted: 04 October 1962 • Published Online: 23 December 2004

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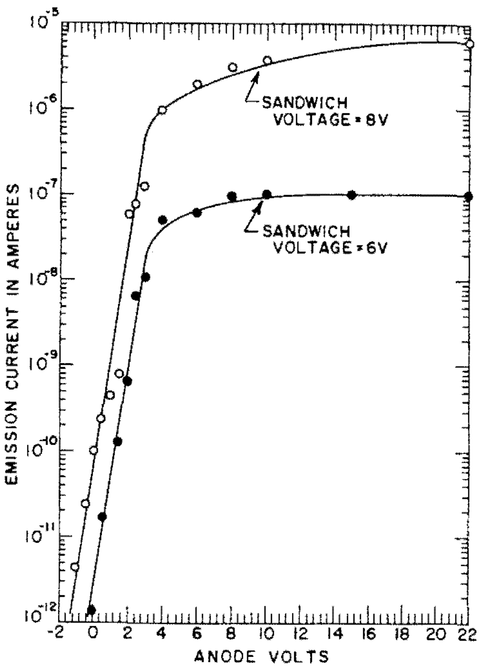

Fig. 2. Relationship of anode current and anode voltage, including the retarding field region.

of the electrons in the conduction band would probably be trapped, and the resulting space charge would increase the height of the tunneling barrier.

Figure 2 shows the relationship between emission current and anode voltage for two different values of sandwich voltage. The emission current saturates at about 22 V and 10 V for sandwich voltages of 8 V and 6 V respectively. A calculation shows that at the higher sandwich voltage the current may be space-charge limited below saturation. From the data in the retarding field region, the mean temperature of the emitted electrons is calculated to be $\sim 4000°$K. The tube has been operating quite stably for over two months.

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STIMULATED EMISSION OF RADIATION FROM GaAs *p-n* JUNCTIONS*

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(Received October 4, 1962)

A characteristic effect of stimulated emission of radiation[1] in a fluorescing material is the narrowing of the emission line as the excitation is increased. We have observed such narrowing of an emission line from a forward-biased GaAs *p-n* junction. As the injection current is increased, the emission line at 77°K narrows by a factor of more than 20 to a width of less than $kT/5$. We believe that this narrowing is direct evidence for the occurrence of stimulated emission.

The GaAs junctions used in this experiment were made by diffusing Zn into GaAs doped with Te. These diodes were bonded onto a Au-plated kovar washer and the junction was etched to an area of approximately 1×10^{-4} cm^2 as shown in the inset of Fig. 1.[2] No attempt was made to obtain highly resonant electromagnetic modes. The diodes were immersed in liquid nitrogen and driven with current pulses as short as 50 nsec at high current levels. The light output was measured using a Perkin Elmer grating spectrometer and a Dumont 6911 photomultiplier.

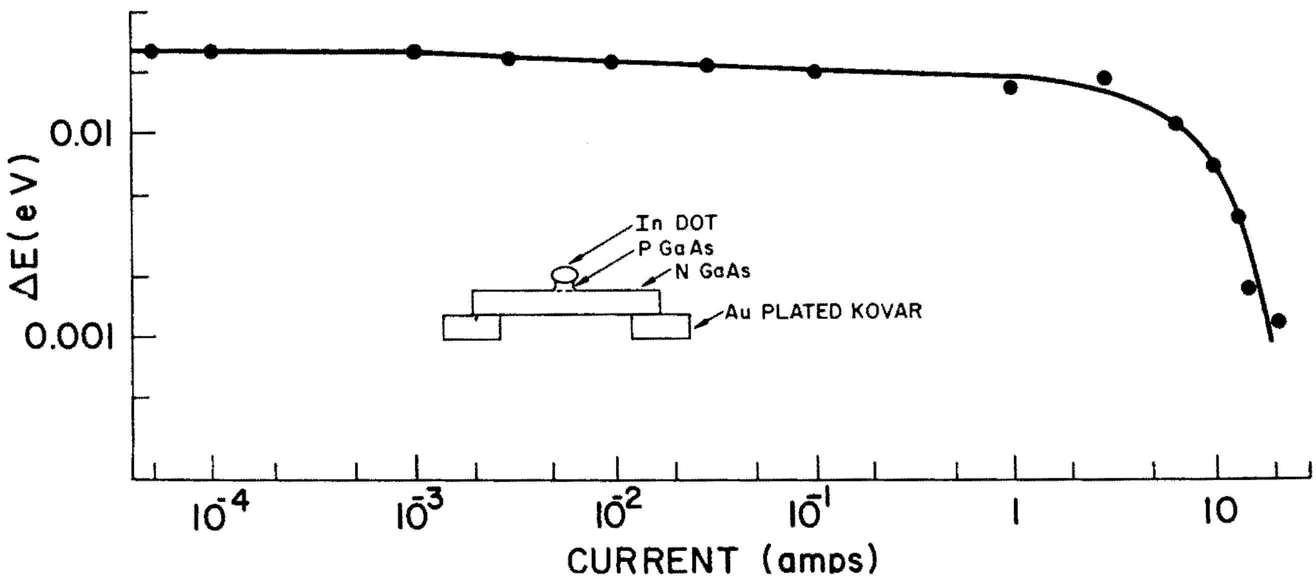

Fig. 1. Full line width at half maximum intensity vs injection current. The area of the diode is 1×10^{-4} cm^2. The inset shows the geometric configuration of the diode.

At low injection levels, it was observed that more than 95% of the light was emitted in a line at 1.47_3 eV with a width at half maximum of 0.026 eV. From photoluminescence experiments we believe the observed line is due almost entirely to transitions between the conduction band and a Zn acceptor level. It has been theoretically shown that such transitions give rise to a relatively short radiative lifetime for holes trapped by the acceptors.

The quantum efficiency per injected electron was greater than 0.2 and perhaps close to 1 for currents greater than 10 A/cm^2. Similar results have been reported by other workers.[2-4] However, unlike the previously reported measurements,[2] we observe constant quantum efficiency for currents greater than 10 A/cm^2.

As the current was increased the half width decreased, at first only slightly, but at currents of 10^4 to 10^5 A/cm^2, the narrowing was striking, as can be seen in Fig. 1.

At high current densities heating of the *p-n* junction, due to its series resistance, causes a shift of the bandgap and, therefore, a shift of the emission line during the duration of the pulse. This shift results in an overestimation of the half-width of the line at currents above 10 A. The line-width values given for currents above 10 A represent only upper limits. In one diode, at the highest currents used, the emission line was resolvable into two lines approximately 6 Å apart and 2 Å wide.

The plausibility of stimulated emission in a *p-n* junction may be appreciated from a simple calculation of the ratio of the number of photons which in the steady state must be present in the crystal to the number of electromagnetic modes within both the crystal and the emission line. If one considers the relationship between the intensity of light emission from the crystal and the density of photons in the crystal, taking into account internal reflection effects, it can be shown that, at a current density of 10^5 A/cm^2, a quantum efficiency of 0.5, and a line width of 0.02 eV, there are 100 photons per electromagnetic mode. With such a photon population radiative emission would be almost entirely stimulated. Narrowing of the emission line and geometrical mode selection would yield a larger photon population per mode but in a fewer number of modes.

The fact that the quantum efficiency is relatively constant for current densities at which the line width narrows rapidly (it is presumed that the photon occupation number of the reinforced modes increases rapidly) is evidence that the quantum efficiency is close to 100%.

The presence of stimulated emission probably has an effect on the high frequency characteristics of the diodes. Under conditions giving high photon occupation numbers, the response time of the diodes should be even smaller than those already reported.[2]

We are indebted to many of our colleagues at the IBM Research Center for their close cooperation.

In particular we thank Drs. R. W. Keyes and R. W. Landauer for stimulating discussions and continuing interest in this work, and Mr. B. Jenkins for technical assistance.

*This work is supported in part by U. S. Army Electronics Research and Development Laboratory, Fort Monmouth, N. J. (Contract DA 36-039-SC-90711)

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A NOTE ON SOME OF THE INTERMEDIATE PHASES IN THE Nb-Sn SYSTEM

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(Received August 3, 1962 and in present form September 17, 1962)

The recent discovery of the superconducting properties of Nb-Sn compounds at magnetic-field strengths of 88,000 G (ref 1) and 150,000 G (ref 2) with current densities of the order of 10,000 A/cm^2 has led to a reexamination of the equilibrium diagram of the Nb-Sn system. Agafonova *et al.*[3] reported only one intermediate phase, Nb_3Sn, in the Nb-Sn system. Reed *et al.*[4] reported three intermediate phases, Nb_3Sn (beta-W structure, stable only above 850°C, melting point greater than 2000°C), Nb_3Sn_2 (tetragonal, c/a = 1.381, peritectic, stable only between 775 and 890°C), and Nb_2Sn_3 (tetragonal, c/a = 0.4435, peritectic at 850°C). Wyman *et al.*[5] reported four intermediate phases present, Nb_4Sn (m. p. 2050°C, solid solution), Nb_3Sn (peritectoid at 730°C between Nb_4Sn and Nb_2Sn_3), Nb_2Sn (peritectoid at 690°C between Nb_3Sn and Nb_2Sn_3), Nb_2Sn_3 (peritectic at 863°C between Nb_4Sn and liquid), and a eutectic (215°C, approximately 83 at. % Sn) between Nb_2Sn_3 and Sn, with all intermediate phases being stable to room temperature.

This note concerns initial work by the Metallurgy of Superconducting Materials Group at the Oak Ridge National Laboratory (ORNL) which disagrees with most of the presently available information on the alloy system as to the number of intermediate phases, their melting points, and their temperature ranges of stability.

"Kunzler"[1] wires, niobium clad (0.015 in. OD × 0.007 in. ID) with a mixture of niobium and tin powder in the core, were heat treated in evacuated quartz capsules for 2, 4, and 16 hr at 1000°C and rapidly cooled, mounted, vibratorily polished,[6] etched lightly, and anodized[7] at 28 V dc. The process of anodizing delineates phases by producing different interference colors on phases having different compositions, allowing distinction between phases that cannot be clearly separated in the microscope and identification of phases through a series of specimens.

Metallographic examination showed at least five phases present in all wire specimens in addition to the niobium clad and a small amount of what had been tin-rich liquid phase. Numerous particles of incompletely reacted niobium powder were present in the core in addition to a considerable amount of porosity (Fig. 1a). The amount of reaction increased with time, but the reaction was far from complete after 16 hr at temperature. X-ray diffraction measurements indicated only Nb_3Sn (ref 8) and Nb present.

Diffusion couples (1/4-in.-diam Nb tubing with a pure tin core, swaged to 0.060 in. OD) were reacted in evacuated quartz capsules for 16 hr at 800, 850, 900, 950 and 1000°C and water quenched. An additional specimen was held at 1000°C for 2 hr, cooled in 5 min to 900°C and held for 1/2 hr, cooled in 5 min to 800°C and held for 1/2 hr, and furnace cooled to room temperature.

Examination of the diffusion couples showed (Figs. 1b, c, and d) four intermediate phases present in the alloy system whose melting points were, in order of increasing tin content: phase 1, greater than 1000°C; phase 2, between 900 and 950°C; phase 3, between 850 and 900°C; and phase 4, less