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Early Work at Lincoln Laboratory on GaAs Semiconductor Devices

Thirty years ago, in May of 1959, Jack Lowen and I gave a talk at the Electrochemical Society meeting, reporting the first gallium-arsenide diffused diodes ever fabricated [1]. Measurements of the diode's switching time clearly showed the usefulness of p-n junction GaAs diodes for high-speed semiconductor components.

Prior diodes in GaAs had been point contacts [2, 3]. The rectification ratios for the diffused diodes were *orders* of magnitude larger than those for point-contact diodes or for an alloy-junction diode described in another presentation at the same meeting [4]. Thus we at Lincoln Laboratory were at the forefront in taking GaAs forward from the point-contact age.

It all started with my decision, supported by management, that my small semiconductor-device group could make a larger contribution to semiconductor-device development if we did not follow the mainstream of research, which was switching from germanium to silicon. We decided, instead, to study gallium arsenide, which promised higher speed because of its higher mobility, and lower leakage currents because of its higher bandgap. In 1958, I visited Professor Welker at Siemens, Erlangen, West Germany, who was the expert on GaAs, and he affirmed our view on the future applicability of this semiconductor. After obtaining our first GaAs material from RCA Laboratories with the help of the Wright Air Development Center, we developed a technique to make p-n junction diodes by diffusing zinc into n-type wafers.

I always remember my surprise at seeing the metallic droplets that miraculously appeared after our first diffusion in a vacuum ampoule. Of course, because we had not used an arsenic atmosphere, the arsenic had evaporated, and the droplets were gallium. We solved this problem by including crushed GaAs, which produced an arsenic atmosphere in the ampoule.

Figure 1, which is an artist's representation of a packaged diode, includes various details of the fabrication process. The indium dot, which was microalloyed into the p-type skin, served as a mask for the etch that defined the p-n junction area, and then as a contact to the p-type region. The package was one that was widely used for point-contact diodes of that era. In our diode, the contact was an ohmic one to the soft top of the indium dot.

The reverse-recovery transient, which limited the speed of the diodes of the time, is plotted in Fig. 2. To obtain the data that showed the 3-ns diode switching time was another challenge [1], and I spent more than two days synchronizing the sweep of a state-of-the-art traveling-wave oscilloscope. Further results [5] were reported in the fall of 1959 and the written publication appeared the following year [6].

In the fall of 1960, we published data on diodes with reverse-leakage currents at room temperature of about 10^{-12} A, using GaAs that was

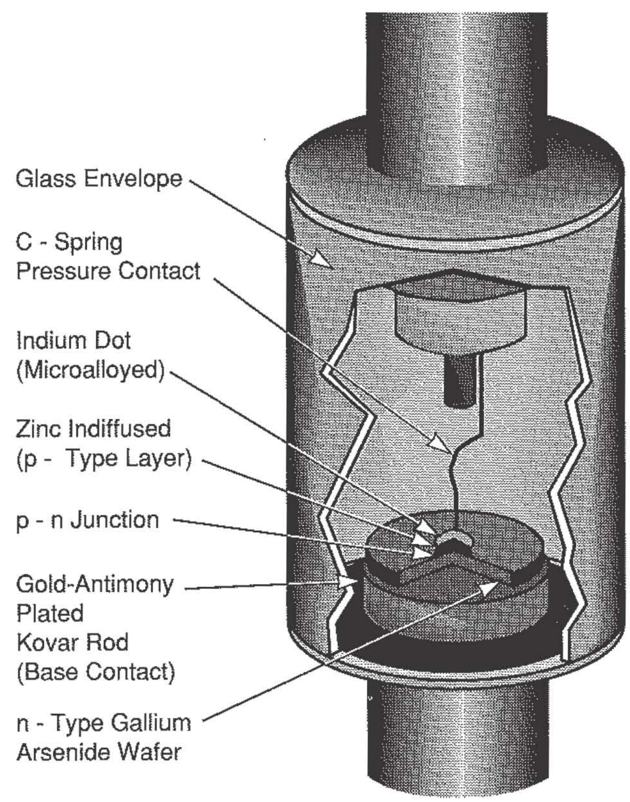

Fig. 1 — Artist's representation of a packaged diode.

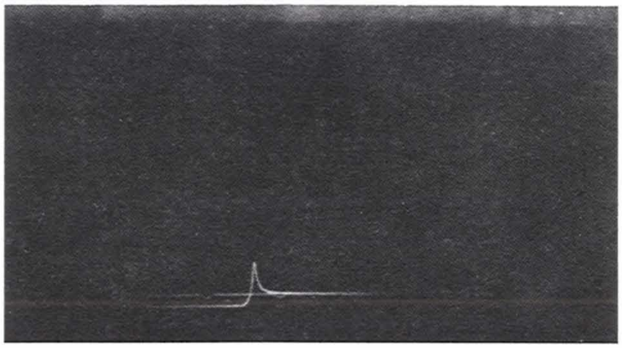

Fig. 2 — Traveling-wave–oscilloscope image of the reverse recovery transient. Also shown is the zero diode-current line, on which two markers 6 ns apart have been superimposed.

now being grown for us by Alan Strauss's group at Lincoln [7]. These results showed that the high-speed GaAs diffused diodes could replace vacuum diodes in applications requiring extremely low leakage.

Jack Lowen and then John Halpern collaborated in the early work; by mid-1960, Ted Quist replaced them in the GaAs program. We then decided also to investigate GaAs alloy diodes. The electrical properties of these diodes differed from those of the diffused diodes, and I suggested to Quist that, as a diagnostic, we look at the recombination radiation of both types of diodes. Quist enlisted Bob Keyes, who had a prism spectrometer, to measure the luminescence.

When the forward-bias luminescence from the diffused diode was measured, the output from the detector pinned the recorder. Keyes had to increase the full-scale reading of the recorder by at least three orders of magnitude and close the spectrometer slits to near zero to bring the reading back on scale. The high-efficiency production of forward-bias luminescence from diffused diodes was reported in July of 1962 [8].

Once we discovered the high-efficiency light emission, we realized that a laser might be possible. We turned our attention to the development of the GaAs diode laser and also to a demonstration of the communications potential of high-efficiency luminescence [9]. After hearing our paper [8], a group at General Electric also decided to start an effort to develop the diode laser [10], and the interest of a group at IBM in developing such a laser increased dramatically [10]. These two groups and ours reported diode lasers in November–December 1962 [11]. The diffused GaAs diode had payoffs that we never anticipated!

Acknowledgment

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