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Room Temperature Delay Times in Diffused Junction GaAs Injection Lasers

Abstract: One nanosecond room temperature delay times at current levels slightly above threshold have been obtained in GaAs injection lasers using a two step diffusion process. Copper contamination is found to leave the delay time unchanged, but increases the rise time.

Introduction

Delay time in injection lasers is defined as the time lapse measured from the leading edge of the current pulse into a laser to the leading edge of the stimulated emission pulse out of the laser. The magnitude of this delay depends inversely upon the amplitude of the input current pulse.[1] Delay time is not to be confused with rise time, which is the time lapse between the start of the stimulated emission pulse and its rise to some arbitrary portion of its maximum amplitude, say 90 percent. Delay times in GaAs injection lasers are about one nanosecond, or much less, at 77°K and, depending on the fabrication process, ten or more times larger at room temperature. The larger room temperature delay time reduces the usefulness of lasers in some applications such as rangefinding.

Carlson reported[2] that a junction diffusion process involving two temperatures can yield lasers that have shorter room temperature delay times than lasers resulting from a diffusion carried out at a single temperature. (Also, room temperature threshold current densities are lower.) Carlson actually preferred, however, to follow the diffusion step with an "annealing" step at about 975°C in an As atmosphere because he found this combination more controllable than the multiple diffusion procedure.

A long term study in this laboratory of the effect of multiple diffusion processes for lasers corroborates many of Carlson's findings, but differs from his results in some important respects. We agree with Carlson that multiple diffusion can reduce room temperature threshold current density and delay time, but, in contrast to his experience with multiple diffusion, we find a particular multiple diffusion process to be very controllable. These observations were made on a large number of lasers cut from more than twenty ingots of GaAs. Carlson does not mention the effects produced by the different sequences of his multiple diffusions or by the cooling rates; we find these parameters to be critical. Whereas Carlson observed that longer delay times resulted when copper was diffused into the lasers, we find delay times to be unaffected by our methods of copper contamination. Some of the differences between our results and those of Carlson may be due to differences in the GaAs ingots; our results (on lasers produced in this laboratory by J. M. Woodall) could not always be duplicated with ingots from other sources.

Experimental

Our lasers were made from Bridgman-grown n-type GaAs ingots doped with tin in the range of (1 to 2.5) × 10^{18} atoms/cm^3. Before diffusion $\{100\}$ or $\{111\}$ slices were chemically polished on one face and sealed with 5 to 10 mg of $ZnAs_2$ in a silica ampoule of about 7 cm^3 volume. Then the ampoule was subjected to the desired temperature cycle. Following the diffusion ohmic contacts were plated on the slices, which were then cleaved and sawed into lasers about $300\mu \times 100\mu \times 100\mu$. The lasers were mounted on various kinds of headers, but most were mounted on a heat sink header described elsewhere.[3] Room

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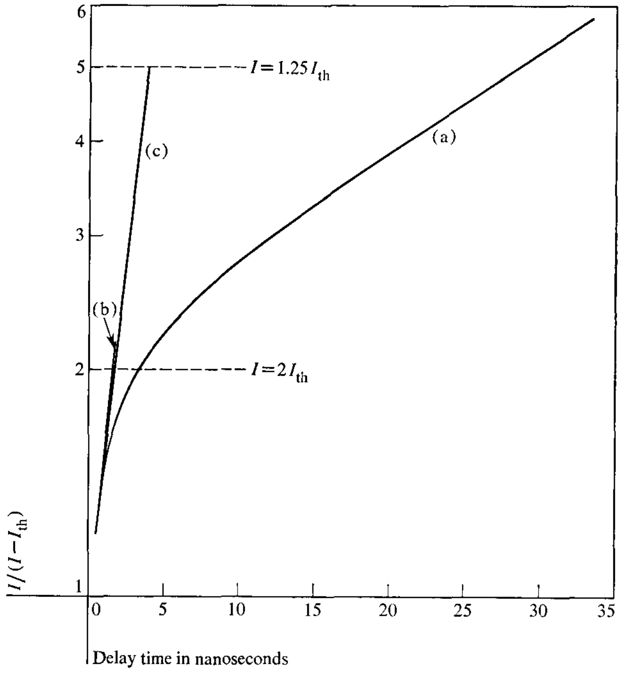


Figure 1 Typical curves of $I/(I\text{-}I_{th})$ vs. delay time: (a) single step diffusion, measurements at 300°K; (b) single step diffusion, measurements at 77°K; (c) two step diffusion, measurements at 300°K.

temperature series resistances are typically 0.04Ω in this mounting and threshold current densities are comparable to those of liquid-epitaxy lasers, namely 35 to 60 kA/cm^2.

The delay times were measured by driving the lasers with a pulse generator—Tektronix 110 (less than 0.25 nsec rise time), Huggins 961D (about 0.5 nsec rise time), or Hewlett-Packard 214A—followed by a pulse amplifier. Pulse lengths varied from 2 to 500 nsec and the actual component used was chosen to be appropriate to the delay time being measured. The light was detected by either a Philco L4501 silicon photodiode (less than 0.1 nsec rise time) or an ITT F4000 vacuum biplanar photodiode (less than 1 nsec rise time) and observed on a Tektronix 661 sampling oscilloscope.

• *Delay time*

When the diffusion is carried out at a single temperature (750°C, 800°C, or 850°C typically) and the ampoule is cooled rapidly or slowly to room temperature, the resulting lasers have relatively long delay times at 300°K and considerably shorter ones at 77°K. When, however, the diffusion is carried out first at 750°C for 16 hours and then at 850°C for 1.25 hours, and the ampoule is quickly cooled by placing it immediately on a transite bench top, the resulting lasers have room temperature delay times as short as those at 77°K. A comparison of the dependence of delay time on current for three types of fabrication is shown in Fig. 1. Here the threshold current is defined as the current for which lasing would occur with infinite delay. In practice this is determined by extrapolating a graph of current vs. the reciprocal of delay time to the intercept on the current axis.

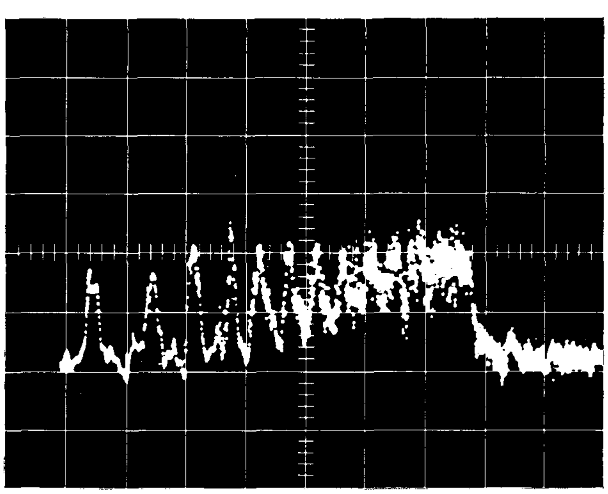
The delay time was determined by subtracting the width of the optical pulse, i.e., the time between the initial rise of stimulated light emission and the start of its decay, from the width of the applied current pulse. Since the rise and fall of stimulated emission occur very sharply and can be measured quite accurately, the limiting factor in the accuracy of the experiments was the measurement of the current pulse width due to its finite rise time.

The reverse sequence (850°C first, then 750°C) does not give short room temperature delays, even if the ampoule is cooled rapidly. With the favored temperature sequence (16 hours at 750°C, then 1.25 hours at 850°C) followed by slow cooling, room temperature delays are longer than when followed by rapid cooling, but are still considerably shorter than for the single temperature case. Interestingly, the favored sequence followed by slow cooling sometimes, but not always, yields lasers whose room temperature light output oscillates as shown in Fig. 2. Such oscillations have not been found in rapidly quenched lasers. The reason for these oscillations is not understood by us, but similar phenomena have been reported recently.[4]

• *Effect of copper*

To investigate the possible effect of copper doping on delay times, deliberate copper contamination was carried out in two ways. First, H. Rupprecht of this laboratory supplied lasers made from three liquid-epitaxy runs. One group

Figure 2 Oscillation in light output at 300°K of certain lasers prepared as described in the text. Lasers were driven with a flat topped, 11.5 A, 40 nsec current pulse. The horizontal scale is 5 nsec per major division.



had no copper in the Ga solution; the next had a nominal concentration of copper in the Ga solution; and the final group had a heavier concentration of copper. Room temperature delay times were short and substantially the same in all three groups. Room temperature threshold current densities were about twice as high as those of the control group with the light copper doping and about three times as high with the heavier copper doping. The presence of copper at the junction was established by an examination of the spontaneous emission spectra. Second, a wafer of GaAs was dipped in a cupric sulfate solution and then put through the two step diffusion process. The presence of copper again was determined by emission spectra. These lasers showed short room temperature delay times. However, the rise times were much longer than those of the control group.

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