This Week's Citation Classic

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Kressel H & Nelson H. Close-confinement gallium arsenide P-N junction lasers with reduced optical loss at room temperature. *RCA Rev.* **30**:106-13, 1969. [RCA Laboratories, Princeton, NJ]

The first practical heterostructure room-temperature operation injection laser is reported. This new single heterojunction AlGaAs/GaAs structure has a threshold current density of 10,800 A/cm^2. This is a factor of five lower than previous typical GaAs homojunction lasers. An explanation for the improvement is presented. [The *SCI*® indicates that this paper has been cited over 110 times since 1969.]

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"I became interested in GaAs laser diodes in 1967. There was a great deal of laser diode research activity at RCA and elsewhere because of the potential utility of these devices. But disenchantment was starting because there were no practical applications of laser diodes owing to their high threshold current densities at room temperature and poor reliability. My first project aimed at elucidating the failure mechanisms, but I rapidly reached the conclusion that the operating current densities were simply too high to allow reliable laser operation at useful duty cycles and power output under normal ambient operating conditions.

"I had the good fortune of working with Herbert Nelson, the inventor of liquid phase epitaxy, and we undertook a systematic effort aimed at improving GaAs lasers using the epitaxial technology.

"Shortly after we launched our program, AlGaAs alloys were prepared by liquid phase epitaxy.[12] The growth of this alloy allowed, for the first time, the fabrication of AlGaAs/GaAs heterojunction structures with negligible lattice parameter mismatch. (This was not the case with GaAsP/GaAs hetero junctions.) The exciting possibility of a low loss and improved confinement laser suddenly dawned. (1) The bandgap step at a heterojunction coincides with a step in the refractive index at the lasing wavelength within the low bandgap region; thus, a much better waveguide can be made. (2) The bandgap step also provides a confining barrier for minority carriers in the low bandgap region. (3) The absorption in the AlGaAs p$^+$-region at the GaAs wavelength is very low compared to homojunction GaAs.

"The first structure we attempted was the simplest one —a single heterojunction device. The first result was a failure. The homojunction control lasers worked as usual but the heterojunction lasers did not lase at room temperature. We then changed the doping level in the AlGaAs p$^+$ layer and the next time around we obtained a twofold reduction in threshold current density to about 18,000 A/cm^2. This clearly showed that we were on the right track. The proper conditions were quickly established and threshold current densities between 10,000 and 12,000 A/cm^2 were subsequently obtained. In fact, publication was delayed until we developed a commercial process for the RCA Solid State Division.

"The probable reason for the frequent reference to our paper is that the single heterojunction laser described in this paper is the first practical room temperature semiconductor laser and represents a significant milestone in the progress of the laser diode from a laboratory curiosity to its present role as a key component in optical communication systems using fibers and other applications. In the paper, we were fortunate in identifying the key elements of heterojunction lasers: improved control of radiation and carrier confinement owing to the heterojunction interfaces. Subsequent lasers such as the double heterojunction laser and the large optical cavity laser operate on these basic principles.

"Research on heterojunction structures has been rewarding. Part of the fun has been to see these devices widely used and the writing of a book on the subject."[3]

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1. **Rupprecht H, Woodall J M & Pettit G D.** Efficient visible electroluminescence at 300°K from $Ga_{1-x}Al_xAs$ p-n junctions grown by liquid phase epitaxy. *Appl. Phys. Lett.* **11**:81-3, 1967.
2. **Kressel H & Hawrylo F Z**. Stimulated emission at 300°K and simultaneous lasing at two wavelengths in epitaxial $Al_xGa_{1-x}As$ injection lasers. *Proc. IEEE* 56:1698-9, 1968.
3. **Kressel H & Butler J K.** *Semiconductor lasers and heterojunction LEDs.* New York: Academic Press, 1977. 608 p.