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# Microsecond-long Lasing Delays in Thin P-clad InGaAs QW Lasers

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*ABSTRACT* Microsecond-long lasing delays have been observed in wide-stripe, thin p-clad, InGaAS single quantum well (QW) lasers with "thick" $p^+$ cap layers. Computer modeling indicates that localized refractive index changes in the cap layer due to ohmic heating from the contact resistance may be the root cause.

High performance capabilities have been reported recently for in-plane diode lasers with thin p-clad, InGaAs quantum well (QW) laser structures [1,2,3]. In such devices, the lasing mode "overlaps" with the contact metallization giving rise to optical mode loss. As a consequence, the modal reflectivity of the metal-semiconductor interface should be high (shiny) in order to minimize this absorption loss [4]. If heat generation from ohmic loss at the metal-semiconductor interface is to be small, the semiconductor material adjacent to the contact metal should be heavily-doped in order to form a current tunneling junction. Since this heavily doped layer is also optically absorbing, trade-offs must be made between optical loss and ohmic heating when designing these shiny contacts. In this work, we report the discovery of a lasing delay phenomenon which appears to be due mainly to localized heating of the heavily-doped cap layer by ohmic loss in the contact resistance. The lasing delay is observed in wide stripe, thin p-clad InGaAs single QW lasers with thick $p^+$ cap layers, where "thick" in this case means 200 nm as shown in Fig.1. A sketch of a scope trace obtained from a typical thick cap laser (50 μm wide x 450 μm long) is shown in Fig.2 and the dependence of the lasing turn-on delay time $\tau_{th}$ with drive current is shown in Fig.3.

In order to understand the reason for these long delays, it is first necessary to recognize that the current densities required to achieved delayed-lasing are very high, ranging from about 3300 to 4700 A/cm$^2$ (see Fig.3). This is to be contrasted with the state-of-the-art value of about 250 A/cm$^2$ for lasers made from the same material with cap thickness values of 100 nm [1]. The main reason for this drastic change in performance with a 100 nm change in cap thickness can be traced to the fact that the lasing mode in a thick cap device has a mode loss coefficient about 14 times larger than that in a thin cap device. As a consequence, the QW gain required for lasing without delay in thick cap lasers is very high. Since QW gain is sublinear with radiative current density at high gain levels [5], very high current densities are required to achieve lasing without delay in such devices (about 9000 A/cm$^2$ according to an exprapolation of the data in Fig. 3). The reason that lasing can occur at lower current densities with delay is due, we believe, to non-uniform heating of the lasing structure by the drive current. One type of non-uniform heating process which could be responsible for the lasing delay phenomenon is depicted in Fig.4. Computer modeling indicates that localized cap heating, due mainly to ohmic loss from the contact resistance, can change the shape of the lasing mode in such a way that net mode gain increases with current on-time until lasing occurs. As a consequence, we believe that this time-delay phenomenon provides a novel means for quantifying localized refractive index changes due to ohmic heating. Such knowledge should prove useful in predicting the performance limitations of thin p-clad lasers in which phase shifts due to refractive index changes are important.

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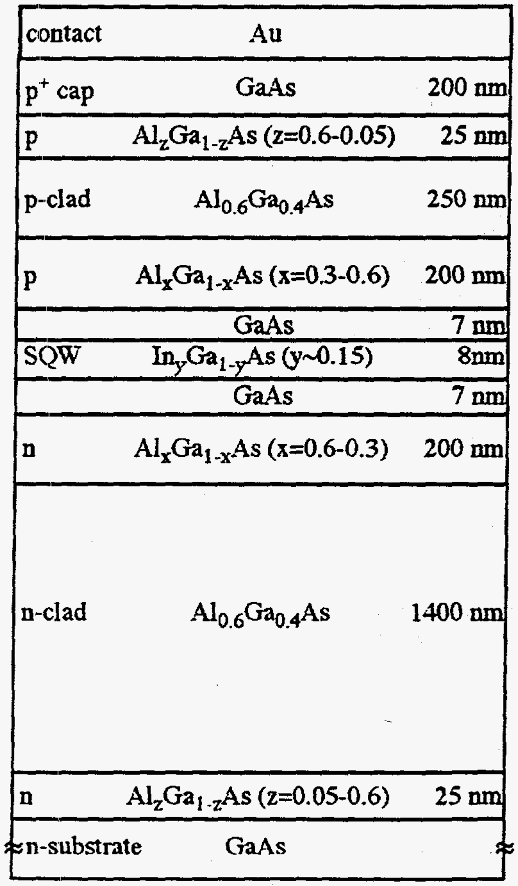

| | | |
|---|---|---|
| contact | Au | |
| $p^+$ cap | GaAs | 200 nm |
| p | $Al_zGa_{1-z}As$ (z=0.6-0.05) | 25 nm |
| p-clad | $Al_{0.6}Ga_{0.4}As$ | 250 nm |
| p | $Al_xGa_{1-x}As$ (x=0.3-0.6) | 200 nm |
| | GaAs | 7 nm |
| SQW | $In_yGa_{1-y}As$ (y~0.15) | 8nm |
| | GaAs | 7 nm |
| n | $Al_xGa_{1-x}As$ (x=0.6-0.3) | 200 nm |
| n-clad | $Al_{0.6}Ga_{0.4}As$ | 1400 nm |
| n | $Al_zGa_{1-z}As$ (z=0.05-0.6) | 25 nm |
| ≈n-substrate | GaAs | ≈ |

Figure 1. Thin p-clad InGaAs diode laser structure.

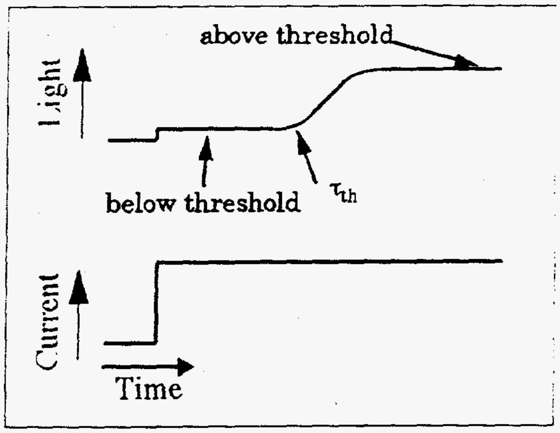

Figure 2. Sketch of a scope trace showing the lasing turn-on delay phenomenon.

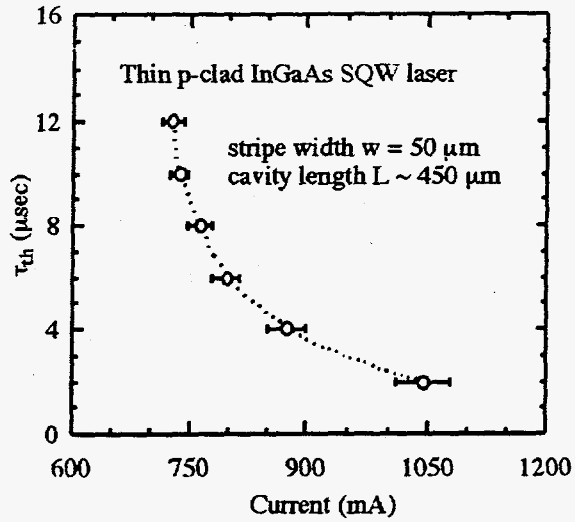

Figure 3. Lasing turn-on delay, $\tau_{th}$, vs. laser drive current. (Current rep. rate = 1 kHz)

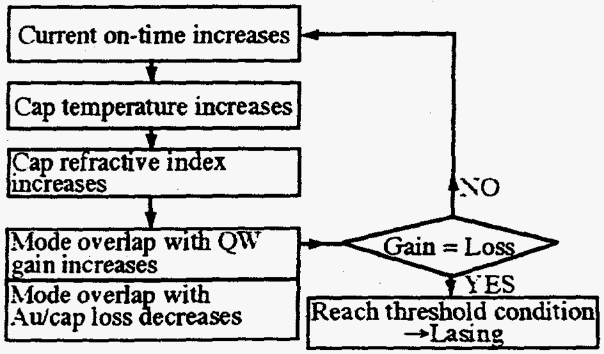

Figure 4. Possible mechanism for lasing turn-on delay phenomenon.