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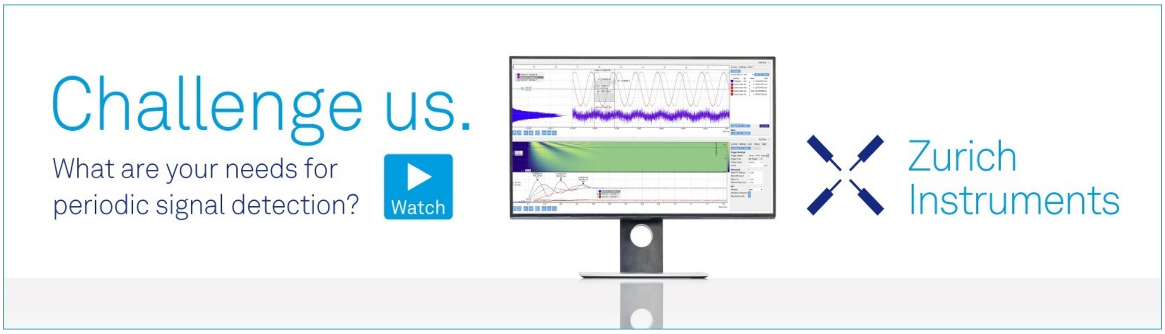

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Laser oscillation in epitaxial GaAs waveguides with corrugation feedback[*]

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Laser action was observed in GaAs epitaxial films using corrugation feedback. The output wavelength was found to depend on the corrugation period. The loss, threshold gain, and feedback parameters were determined and compared with theoretical predictions.

We have recently observed laser action at 0.83 μ from optically pumped GaAs crystals in which the feedback was provided by surface corrugation.[1] The threshold pump level is expected, as in the case of injection lasers, to depend strongly on the optical confinement which, in the case described above, was due to the inverted layer. For this reason it was decided to extend the experiment to epitaxial GaAs dielectric waveguides. In addition, the controlled optical confinement makes possible a comparison of the laser performance with that expected theoretically.

Two different dielectric waveguides as illustrated by Fig. 1 were used in the experiment. The first [Fig. 1(a)] consisted of an epitaxial GaAs layer 3 μ thick with a carrier concentration $n\approx 6\times 10^{16}$ cm^{-3} on a GaAs substrate with $n\approx 10^{18}$ cm^{-3}. The second guide was a GaAs-$\mathrm{Ga}_{1-x}\mathrm{Al}_x\mathrm{As}$ ($x\approx 0.3$) double layer on a GaAs substrate. The thickness of the guiding GaAs layer was 3 μ.

The surface corrugations with a depth of 500 Å were produced by ion milling through a photoresist mask produced by laser interference as previously described.[2] The samples were pumped optically at 77 °K by using a repetitively pulsed dye laser (rhodamine B) tuned to $\lambda_p = 6300$ Å. The individual pumping pulses had a duration of $\sim 7\times 10^{-9}$ sec and a peak power of ~2 kW. Cylindrical lenses were used to pump a rectangular strip 0.3 mm wide of a variable length.

The corrugation period Λ was approximately 0.35 μ so that Bragg coupling between the forward- and backward-traveling waves was due to the third Fourier component of the corrugation function, which led to oscillation at

$$\lambda = \tfrac{2}{3} n_g \Lambda, \tag{1}$$

where n_g is the effective mode index of refraction and for our case was nearly equal to the guiding layer index. A number of waveguides were prepared with different corrugation periods. The measured oscillation wavelength λ of the samples is plotted in Fig. 2 as a function of the period. The periods were measured from the angular position of Bragg reflection orders using a He-Ne 0.6328-μ laser. The accuracy of the period determination is ±3 Å. A tuning range of ~45 Å was spanned by varying the period between 3450 and 3476 Å. The straight line drawn through the data points is a plot of Eq. (1) with $n_g = 3.59$. We thus conclude that the laser feedback is indeed caused by the corrugations and that their use leads to a stabilization of the output wavelength.

The threshold pumping intensity for both samples [Figs. 1(a) and 1(b)] was $\sim 10^4$ W/cm^2. This is to be compared with a pumping threshold of 2×10^5 W/cm^2 in the case of corrugated bulk GaAs.[1] This improvement by a factor of 20 is attributed to the improved confinement which leads to a reduction of the losses, an increase in the Bragg coupling, and the optical gain.

The basic parameters characterizing the laser action are (i) the exponential gain constant g and the gain factor β, where

$$g = \beta I \tag{2}$$

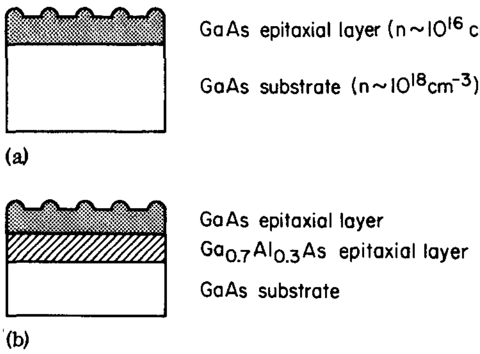

FIG. 1. Cross sections of GaAs distributed-feedback lasers. The thickness of the top GaAs epitaxial layer is 3 μ.

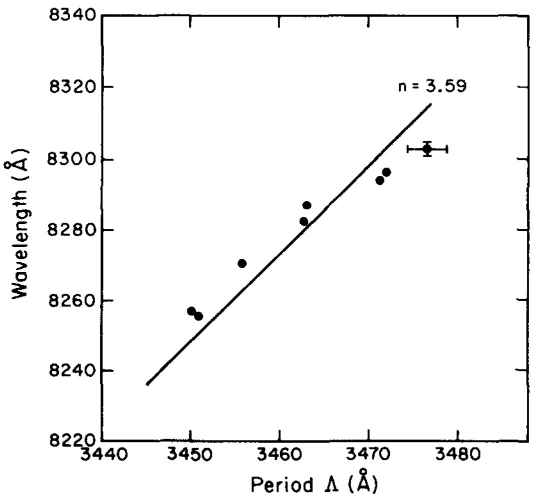

FIG. 2. Oscillation wavelength as a function of corrugation period. The solid line is calculated using Eq. (1) with $n_g = 3.59$.

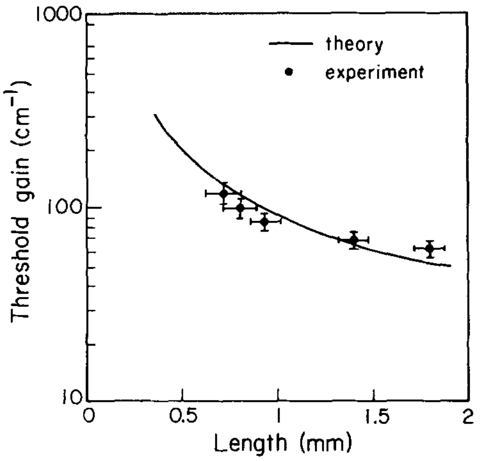

FIG. 3. Threshold gain of a distributed-feedback laser. Experimental points were obtained using $\beta = 5$ cm/kW. The thickness of the GaAs epitaxial layer was 3 μ, and the depth of the corrugation was 500 Å.

with I as the pumping intensity; (ii) the residual bulk loss constant α_0; (iii) the loss constant α_{rad} due to lower-order Bragg radiation by the corrugation; and (iv) the Bragg coupling constant κ.

The gain constant β and the bulk loss α_0 were determined from measurements of the superradiant power (amplified spontaneous emission) in an uncorrugated waveguide, as a function of the length of the pumped region.[3] The result is $\alpha_0 = 5$ cm^{-1} and $\beta = 5$ cm/kW for the epitaxial GaAs-on-GaAs waveguide [Fig. 1(a)] at 77 °K.

The gain coefficient β is of special interest. Assuming that each pump photon excites one electron-hole pair, we can relate the observed gain to an equivalent electrical injection current density J in (A/cm^2). We thus have

$$g = \beta' J, \tag{3}$$

where $\beta' = \beta h\nu_{\text{pump}/e} = 9.8$ cm/kA for $\beta = 5$ cm/kW, which is about one-third of the β' observed at 77 °K in single-heterojunction injection lasers with a confinement distance of ~2 μ.[4]

The radiation loss α_{rad} was determined in a separate experiment to be $\alpha_{\text{rad}} = 10$ cm^{-1}.

The threshold gain constant for a laser of length l is

$$g_{\text{th}} = g^0_{\text{th}}(\kappa, l) + \alpha_0 + \alpha_{\text{rad}}, \tag{4}$$

where g^0_{th} is the threshold gain constant of a lossless distributed-feedback laser of length l and coupling coefficient κ.[5]

Figure 3 shows experimental data points of g_{th} for different values of the length l of the pumped region. The solid curve is a theoretical plot of Eq. (4) using $\alpha_0 + \alpha_{\text{rad}} = 15$ cm^{-1} and a value of $\kappa = 1.93$ cm^{-1} obtained from the relation[6]

$$\kappa = \frac{2\pi^2}{3m\lambda}\frac{n_2^2 - 1}{n_2}\left(\frac{a}{t}\right)^3\left(1 + \frac{3}{2\pi}\frac{\lambda/a}{(n_2^2 - 1)^{1/2}} + \frac{3}{4\pi^2}\frac{(\lambda/a)^2}{(n_2^2 - 1)}\right) \tag{5}$$

for $a = 500$ Å, $n_2 = 3.6$, $t = 3$ μ, $\lambda = 0.83$ μ, and $m = 3$.

In conclusion, epitaxial GaAs lasers have been operated by using corrugation feedback. The dependence of the output wavelength on the period was demonstrated. The interplay of the gain, loss, and feedback mechanisms in achieving laser action is pointed out. An optimization of these parameters, now under way, could lead to substantially lower thresholds.

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