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Pressure Induced Polarization Ellipticity in Injection Lasers*

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Departure from linear polarization of laser modes was observed to be induced by applied uniaxial stress. The induced polarization ellipticity was observed to be independent of injection current but a function of applied stress and of the individual laser. Non zero ellipticity was observed in some lasers even at threshold.

Variações na polarização linear dos modos de emissão de lasers de injeção podem ser induzidas pela aplicação de pressões uniaxiais. Observa-se que a polarização elíptica induzida é independente da corrente de injeção mas depende da pressão aplicada e das características individuais de cada laser. Polarização elíptica diferente de zero pode ser observada mesmo no limiar de emissão estimulada.

1. INTRODUCTION

In most injection lasers the modes of the laser cavity are predominantly linearly polarized with the electric field parallel (TE) or perpendicular (TM) to the junction plane [1-3]. In the present paper we show that uniaxial pressure can induce the mode polarization to become elliptical with the degree of ellipticity being a function of pressure and of the individual laser diode.

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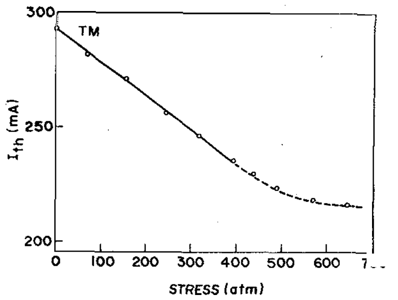


Fig.1 - Typical uniaxial pressure dependence of threshold of a homostructure laser.

In a previous publication[4] we reported on the variation of the threshold current of GaAs injection lasers when subjected to uniaxial pressure. There we showed that for a laser operating in a TE mode, the threshold current I_{th} increases with pressure P up to a certain point where the lasing mode changes to TM and then the threshold current decreases with futher increase in pressure. For a laser operating in a TM mode the threshold just decreases with increasing pressure. These results were explained in terms of variations of the gains of TE and TM modes caused by the splitting of the heavy hole and light hole valence band degeneracy of GaAs upon application of uniaxial pressure.

In Fig. 1 we show a typical I_{th} vs. P curve obtained experimentally.

The departure from linearity of the threshold-pressure dependente above 400 atm. was suspected to be due to junction damage by the pressure, as the experimental points could not be retraced upon reducing the pressures. But in many other lasers we have studied since, we have observed such non linear behaviour of the threshold curve which is perfectly reversible upon reducing the applied pressure and the results can be traced and retraced many times over.

This eliminates junction damage as a possible cause for the observed behaviour of I_{th} in these lasers. We have examined the properties of these lasers in this region in detail and report them in this paper together with a possible explanation based upon the modification of the eigenmodes of the laser waveguide caused by the uniaxial pressure induced changes in the refractive index tensor of GaAs.

2. EXPERIMENTAL

The lasers studied were stripe-geometry GaAs homostructure lasers made by zinc diffusion into a Sn doped substrate oriented in a (111) plane. The approximate physical dimensions of the laser diodes were 380 µm long by 630 µm wide by 100 µm thick, with a stripe width of 13 µm.

The exact dimensions of each device were measured with a microscope before applying the pressure. The experimental arrangement used to apply uniaxial pressure perpendicular to the junction has been described before[4], except that it was adapted[5] to operate at temperatures near 77°K. To rninimise heating effects the lasers were operated with 100 ns current pulses at a low duty cycle. The resulting light output was collected with a lens, analysed with a polariser and detected with a photomultiplier. DC outputs proportional to the amplitudes of the current and light pulses, needed to drive the x and y channels of a pen-recorder, were obtained using sampling oscilloscopes and box-car integrators. All data were taken with the lasers operating near 85°K.

3. RESULTS AND COMMENTS

The threshold current and the components of the mode polarization along the TE and TM directions were obtained by recording the light output intensity with TE and TM polarization as a function of current. Their pressure dependence was determined by repeating the measurements with various uniaxial pressures applied to the laser.

As is shown in Fig. 2, for laser M-9, the ratio, TE/TM, of the mode component intensities along TE and TM directions was determined by subtracting the spontaneous emission intensity value at threshold from the TE and TM intensity at some fixed current above threshold and then dividing one by the other. It was verified that this ratio was the same for all currents above threshold (up to a current where a higher order mode with a different polarization ellipticity started oscillating). It should be noted that the relatively well-marked threshold current is the same for both the TE and the TM components. This feature and the fact that the TE/TM intensity ratio remains constant within a certain rangeof current above threshold were observed in all the measurements we carried out on various lasers. These two facts together seem to rule out the possibility that we are observing two (or more) modes having linear polarizations orthogonal to one another.

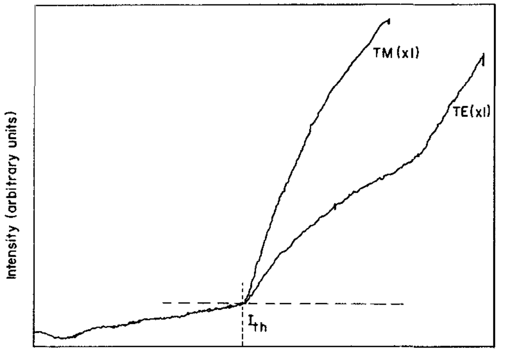


Fig.2 - Typical current dependence of output intetisity frorn a laser measured through a polarizer. Both polarizations are shown; the ratio between the outputs at each polarization is constant once the unpolarized spontaneous emission i5 subtracted. This ratio is different for other values of applied pressure.

The variation of the intensity ratio TE/TM and the threshold current with uniaxial pressure, for laser M-3 are shown in Figs. 3(a) and 3(b) respectively.

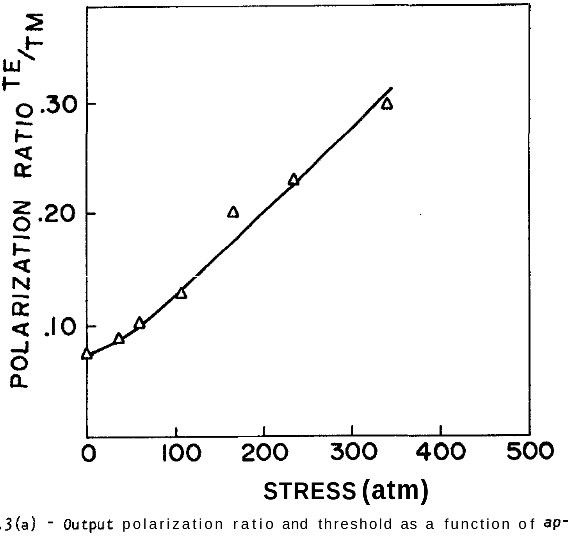


Fig.3(a) - Output polarization ratio and threshold as a function of applied uniaxial pressure.

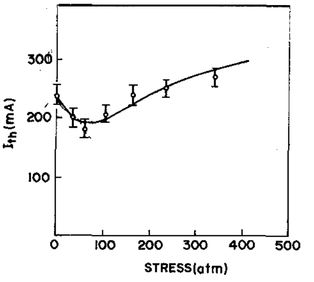


Fig.3(b) - Output polarization ratio and threshold as a function of applied uniaxial pressure.

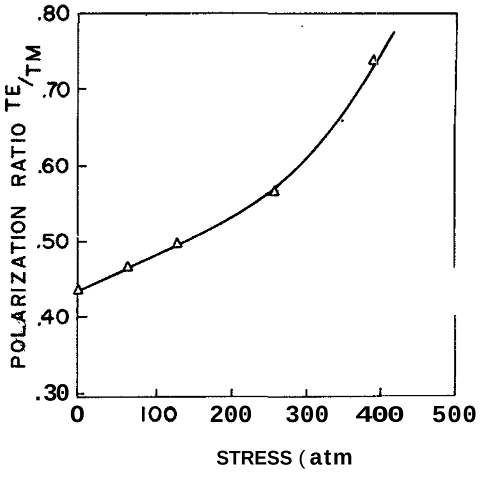
We see that the ratio TE/TM and hence the mode ellipticity increases with uniaxial pressure.

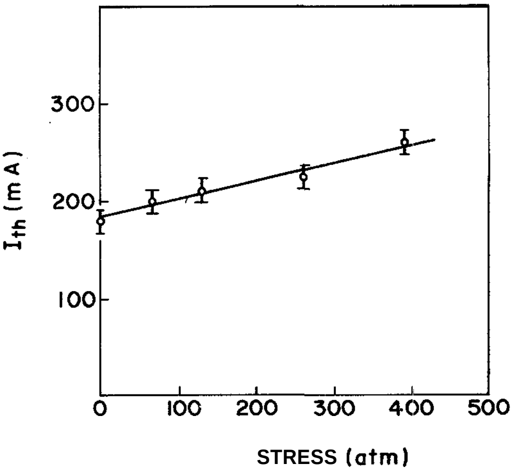
We think this is caused by the steady state (oscillator) equivalent of mode conversion in a transmission structure[6], where the pressure induced off-diagonal terms in the refractive index tensorwouldtend to cause admixture of TE and TM modes. The nearer the propagation constants of these modes the greater the mode admixture at a given pressure. In the steady state case the effect of this mode conversion would manifest itself as an increased ellipticity of the eigenmodes of the laser cavity. Also since the threshold of themode complementary (TE in our case) to the lasing mode (TM in our case) is higher than the threshold of the latter, an admixture that has an increased component of the former should have a higher overall threshold. We observe this effect in Fig. 3(b) where the decreasing threshold rounds off and then increases with pressure.

Similar results for laser M-9 are shown in Fig. 4.

Here the laser mode already starts off at zero pressure with a high degree of ellipticity (probably due to internal strains) and the threshold current just increases with pressure.

Eventually, with a sufficiently large perturbation, the case of complete power sharing between the modes should be represented in the steady state case by a mode ellipticity such that TE/TM is nearly unity. Further increase in the perturbation should not affect the mode ellipticity and consequently should not affect the threshold also. In Fig. 5 we





Figures 4(a) and 4(b) - Polarization ratio and threshold curve for a laser with large ellipticity at zero applied stress. This case was rare and probably indicated a relatively large internal strain.

show the results obtained for laser M-12, where these condition of mode and threshold stability are realised at sufficiently high pressures.

Observations of the polarizations angles at which maximum and minimum intensities occur and the variations of these angles with applied uniaxial pressure lend further support to our contention that the modes are elliptically polarized. Typically for a laser which without applied pressure has a very small TE component, the polarization angle for mini-

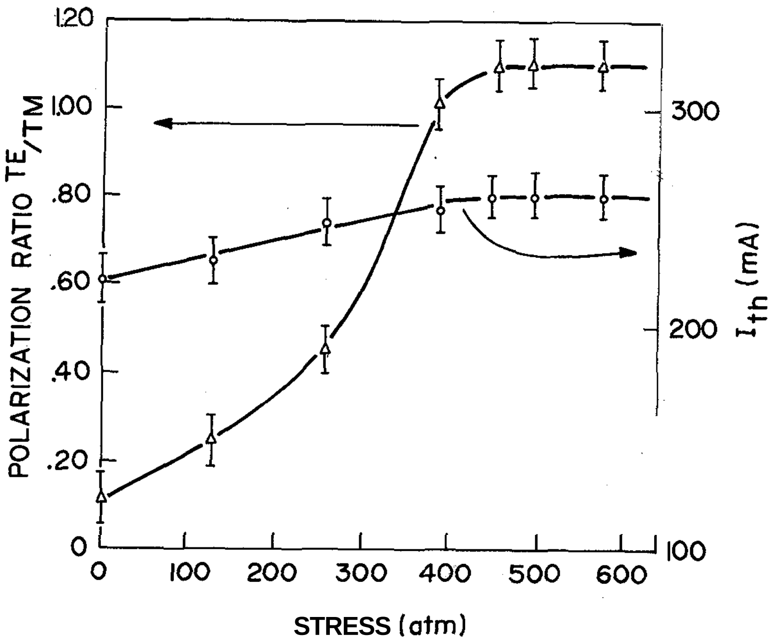


Fig. 5 - polarization ratio and threshold curve for a laser on which the applied stress was large enough to obtain near unity polarization ratio; as expected the threshold also became pressure independent.

mum intensity (taking the TE axis as 0^{o} and the TM axis as 90^{o}) is 90^{o} without applied pressure. This angle increases uniformly (though not necessarily linearly) with applied uniaxial pressure until it reaches some value between 125^{o} and 150^{o} and then does not change anymore for higher pressures. This levelling off of the minimum intensity polarization angle occurs at about the same applied uniaxial pressure as for the levelling off of the TE/TM ratio and the threshold current. The maximum intensity polarization angle accompanied the variation of the minimum intensity polarization angle and always remained at right angles with the latter.

4. CONCLUSIONS

Although some polarization ellipticity was shown to be expected in the semiconductor laser modes by Zachos *et al.*[1], even from a scalar dielectric constant considerations, the values encountered here are larger by orders of magnitude.

This indicates that pressure does induce off-diagonal elements in the dielectric constant tensor, leading to mode conversion by photo-elastic effect. This was unexpected since the pressure was applied in the (111) direction and pure uniaxial stress in this direction does not produce off-diagonal elements in the dielectric constant tensor[7]. However as shown by Yariv[6] of the TE and TM modes are nearly degenerated in their propagation constants, as is the case in homostructure lasers, substantial mode conversion can occur even if the off-diagonal elements are small, suggesting that in our case the stress is not exactly in the (111) direction. This also explains why the ellipticity is so dependent on the individual laser since the deviation from the (111) uniaxial stress, the already existent internal strain, and the exact value of the propagation constants difference between the TE and TM modes does vary from laser to laser.

The mode conversion is further enhanced by the feedback inherent in the lasing process: a theory of this behaviouris presently being developed and will be published shortly.

Finally it is worth observing that in double heterostructure lasers where the propagation constant difference between TE and TM modes is relatively large, mode ellipticity was ocasionally observed by Paoli[8] but as expected is much smaller than the one observed by us.

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