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B-7-4 High Speed Repetitive Q-Switching in Semiconductor Acoustic Distributed Feedback Lasers

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We proposed an acoustic distributed feedback (ADFB) laser[1] as an extension of distributed feedback (DFB) laser.

An intense surface acoustic wave (SAW) at GHz range, needed to realize the ADFB laser, has been excited on GaAs by mode conversion from bulk wave.[2] Also, we have demonstrated the oscillation of the two-dimensional DFB laser[3] which simulated the operation of the proposed ADFB laser. The above facts encourage us to realize the ADFB laser. On the other hand, Tsukada and Tang proposed Q-switching semiconductor laser, based on electro-optic switching of the Bragg reflectivity of the grating reflectors.[4] Here, we propose a high speed repetitive Q-switching laser where acoustic standing waves in the DFB cavity are used.

Principle When oppositely propagating SAW's are injected into a distributed Bragg reflector (DBR) laser (see Fig.1), the y-directed spatial variation of the refractive index, due to the SAW's, are written in a form of a standing wave:

$$\begin{aligned}\Delta n_a(y,t) &= \Delta n_a \cos(Ky-\Omega t)+\Delta n_a \cos(Ky+\Omega t+\phi)\\ &= 2\Delta n_a \cos(\Omega t+\tfrac{\phi}{2})\times\cos(Ky+\tfrac{\phi}{2})\\ &\equiv \Delta N_a(t)\cos(Ky+\tfrac{\phi}{2})\end{aligned} \qquad (1)$$

We can expect to have a laser where Q value of the two-dimensional ring mode[1)3)] changes periodically at the frequency of $(2\Omega/2\pi)$.

We next discuss the characteristics of the Q-switchings quantitatively. In the situation, represented in Fig.1(a), the reflection coefficient from the SAW's is given in the form of

$$R_a=-i\sin(2\pi\ell\Delta N_a(t)/\lambda_0\cos\theta_a) \qquad (2)$$

In the case of Fig.1(b), the reflection coefficient is given as follows:

$$\begin{aligned}R_a=&-i\sin(2\pi\ell\Delta N_a(t)/\lambda_0\cos\theta_a)\\ &\times[1+R_g{}^2\cdot e^{2g\ell/\cos\theta_a}\cdot e^{-2ik\ell/\cos\theta_a}\\ &\times\cos^2(2\pi\ell\Delta N_a(t)/\lambda_0\cos\theta_a)]\end{aligned} \qquad (3)$$

which includes the effect that a transmitting light wave is reflected from gratings and SAW's and return to the original point, shown as dashed line in the Fig. 1(b). In eq.(3), R_g is reflection coefficient from the grating and is represented by the loss coefficient α in the grating region ($\frac{\ell}{2}<|z|<\frac{L}{2}$), the wave number of the grating k_g, the coupling constant of the grating κ_g, the wave number of the optical wave k, and the incident angle θ_a.[1] We can estimate the threshold gain g_{th} for oscillations from eqs.(1)(2)(3) and the following oscillation condition.

$$R_g R_a e^{g\ell/\cos\theta_a}\cdot e^{-ik\ell/\cos\theta_a}=\pm 1 \qquad (4)$$

Now, we consider the simplest and most interesting case[1] i.e. $k\ell/\cos\theta_a=N\pi$ (N:integer). The condition is satisfied by the SAW with a proper frequency.[1] In this case, the laser frequency of the 2-D.mode is equal to the Bragg frequency of the grating and the required threshold gain is the lowest. Numerical example of the threshold gain ($g_{th}L$) as a function of time Ωt is shown in Fig.2. As shown in Fig.2, switching characteristics for the situation (b) are almost ideal. The sharp switch-on (-off) behavior is due to the fact that the phase of the multiple reflected wave, indicated by dashed lines in Fig.1(b), is opposite to that of the single reflected wave, indicated by solid line in the figure.

Dynamic behavior Assuming that the switching of the Q value was essentially instantaneous and using rate equations[4], we estimated the delay time Δt., pulse width $\Delta t_{1/2}$ and the pumping rate P, needed to sustain repetitive Q-switching. Here, an example of the results is shown. For the case of gain exponent m of 2, the pumping rate P of $\sim 4.5P_{th}$, and the frequency of SAW's of 1.5GHz, we can expect to have a laser which has a characteristic as shown in Table.1. In the analysis, we assumed that the gain coefficient g is expressed in the semiconductor as follows:

$$g=Bn^{m} \quad (m=1.5\sim 3).$$

Finally, the suppression of the oscillation of one-dimensional mode will be required for successful Q-switching of 2-D.mode. For example, when the SAW's at the frequencies of 1.5GHz for GaAs are used, the separation of the laser wavelength between one- and two-dimensional modes is about 20Å. Therefore, by matching the wavelength of the 2-D.mode to peak gain wavelength, the above requirement will be satisfied.

References

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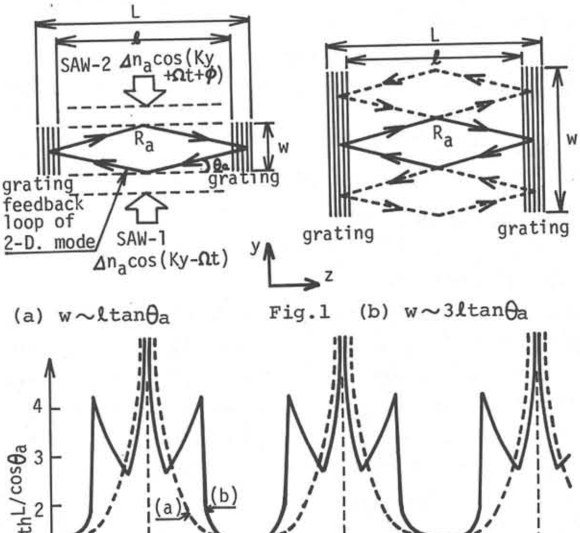
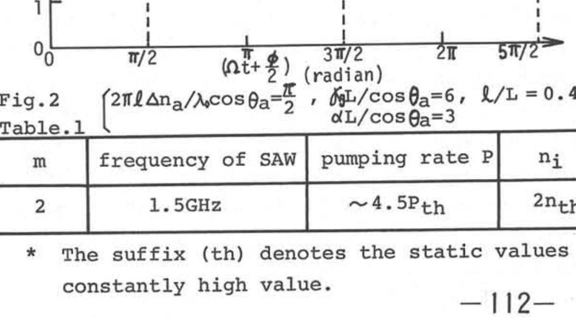


(a) $w\sim \ell\tan\theta_a$ Fig.1 (b) $w\sim 3\ell\tan\theta_a$



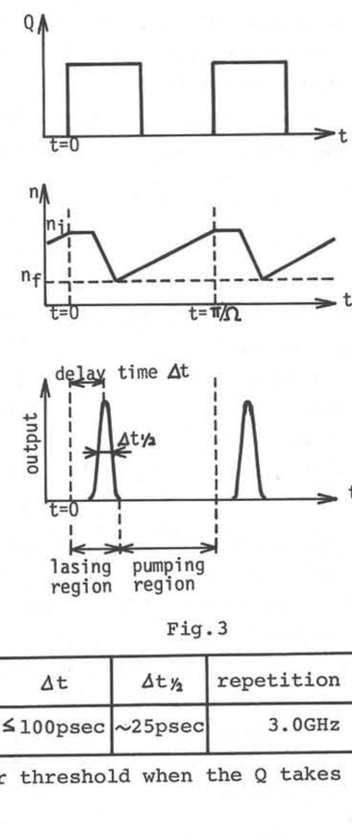


Fig.2 $\left[2\pi\ell\Delta n_a/\lambda_0\cos\theta_a=\frac{\pi}{2},\ \kappa_0 L/\cos\theta_a=6,\ \ell/L=0.4,\ \alpha L/\cos\theta_a=3\right]$

Fig.3

Table.1

m	frequency of SAW	pumping rate P	n_i	Δt	$\Delta t_{1/2}$	repetition rate
2	1.5GHz	$\sim 4.5P_{th}$	$2n_{th}$	$\leq$100psec	$\sim$25psec	3.0GHz

* The suffix (th) denotes the static values for threshold when the Q takes constantly high value.