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Polarization Bistability of Vertical Cavity Lasers under External Optical Injection

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Vertical cavity lasers (VCL's) with external optical injection have the potential applications in all-optical switching and optical memory due to the properties of dispersive bistability [1]. In this paper, the polarization bistability of VCL's is studied theoretically with the consideration of dielectric Bragg reflectors, surface coatings, carrier induced refractive index inside the active layer as well as the intensity and wavelength of the injected light.

In the calculation, the orthogonal TE polarization states are assumed to be polarized in the X and Y directions which are parallel and perpendicular to the crystal plane (011), respectively. It is assumed that anisotropic stress has been applied on the active layer and the X–polarized light is lasing for the VCL's biased above threshold. The polarization switching mechanism in VCL's can be considered as gain quenching induced by the input Y–polarized light. The gain in the cavity is depleted in the process of amplifying the Y–polarized light, and thus the X–polarized mode oscillation is suppressed. The change in carrier concentration which accompanies the amplification of Y–polarized mode also causes a refractive index change in the cavity. Inside the active layer, the decrease in the carrier concentration causes an increase in the refractive index. If the wavelength of the input Y–polarized light is set slightly longer than that of the Y–polarized light cavity wavelength without external optical injection, one can observe dispersive bistability in both X– and Y–polarization output [2].

In order to model the dispersive bistability described above for the VCL's, it is assumed that simultaneous Y–polarized light amplification takes place when a Y–polarized light is injected into a laser diode. The inclusion of carrier consumption due to the Y–polarized light injection can be introduced into the rate equation of carriers. The photon density of the X–polarized light can be described by photon rate equation. The optical field distribution inside the laser cavity can also be calculated through the matrix method and a self-consistent model for VCL's under external optical injection is obtained.

Fig 1. shows the schematic of VCL with a built-in index guided structure. The GaAs-$Al_{0.3}Ga_{0.7}As$ quantum well active layer is sandwiched between two undoped spacer layers and two Bragg reflectors, which provide optical feedback for lasing. The undoped spacer layers have thickness of half-wavelength each and the Bragg reflectors are formed by alternating layers of AlAs and AlGaAs with quarter-wavelength thickness, and consist of n and m such dielectric layers on both the n- and p-side, respectively. The active region consists of three GaAs-$Al_{0.3}Ga_{0.7}As$ quantum wells with well width of 100Å and the total thickness of the active layer is half-wavelength.

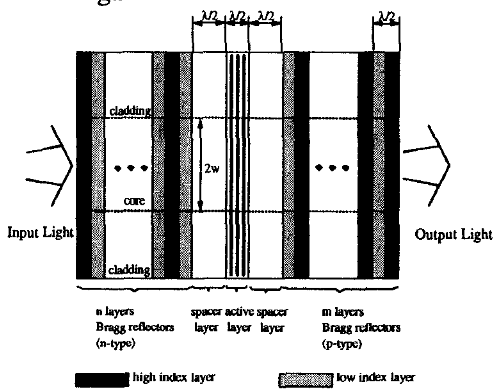

Fig 1. Schematic of an index guided vertical cavity laser used in our analysis. n and m is the number of dielectric layers on the left and right hand side of the Bragg reflectors.

First, we analyze VCL's of symmetric Bragg reflectors (i.e. n=m) with AR coatings on both surfaces. Fig 2 shows the typical output Y–polarized light ($P_{Y_{out}}$) characteristics under influence of injected Y–polarized light ($P_{Y_{in}}$) with longer detuned wavelength (+Δλ).

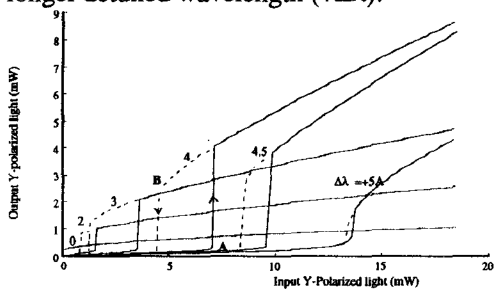

Fig 2. Y–polarized light output versus Y–polarized light input with input Y–polarized light detuned to longer wavelength (+Δλ). Solid line – forward process and dotted line - reverse process.

The influence of $\pm\Delta\lambda$ and Bragg reflectors (i.e. number of n and m) are summarized as follows: 1) no hysteresis loop is observed for $-\Delta\lambda$, 2) the range of $+\Delta\lambda$ to achieve bistable operation is increase with the reduction of n and m and 3) the magnitude of injection power is in order of 10 mW. As we can see, the range of $+\Delta\lambda$ can be fully controlled by the design of Bragg reflectors, however, the injection power required to trigger the bistable operation of VCL's is too high for all-optical switching and optical memory application. Therefore, significantly reduction of P_{Ymax} is essential.

Now we considered the case for VCL's of symmetric Bragg reflectors without AR coatings. Fig 3 shows the typical P_{Yout} characteristics under the influence of P_{Yin} with $+\Delta\lambda$. The characteristics of P_{Yout} behaves differently to that given in Fig 2. It is noted that overshoot of P_{Yout} is observed at the 'switch-on' position but P_{Yout} remains constant with further increase of P_{Yin}.

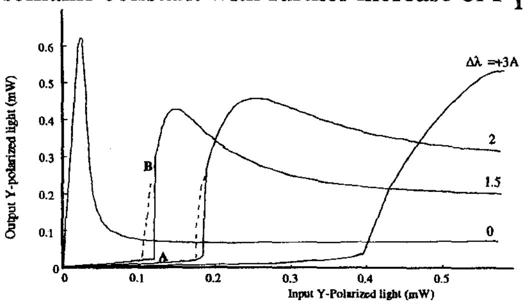

Fig 3. Y–polarized light output versus Y–polarized light input with input Y–polarized light detuned to longer wavelength (+Δλ). Solid line – forward process and dotted line - reverse process.

The influence of $\pm\Delta\lambda$ and Bragg reflectors on the bistable operation of VCL's without AR coatings can also be summarized as follows: 1) No hysteresis loop is observed for P_{Yin} with $-\Delta\lambda$. 2) The reduction of dielectric layers (i.e. number of n and m) enhances the range of $+\Delta\lambda$ to achieve bistable operation and 3) The magnitude of P_{Yin} is reduced to less than 1mW for bistable switching operation which is more preferred than VCL's with AR coatings due to low injection power is required.

we also investigate VCL's of asymmetric Bragg reflectors (i.e. $n \neq m$) with and without AR coatings. It is found that for all cases (different combination of n and m), the characteristics of P_{Yout} versus P_{Yin} are similar to Figs 2 and 3, hysteresis loops are observed for some $+\Delta\lambda$ of P_{Yin} but no bistable operation is obtained for P_{Yin} of $-\Delta\lambda$. The characteristics of VCL's under optical injection can be summarized as follows: 1) The range of $+\Delta\lambda$ is mostly determined by the magnitude of total optical loss and is less dependent on the combination of n and m as well as surface reflection. 2) If $n>m$, high P_{Yin} is required for the polarization bistable/switching process. 3) If $n<m$, low P_{Yout} due to the high reflectivities of Bragg reflector. 4) Surface reflection reduces the amount of P_{Yin} for the excitation of Y–polarized light. From the above analysis, we can conclude that the configuration of VCL with asymmetric Bragg reflectors is not recommended for the utilization as optical switch or optical memory. This is because no extra advantage is obtained when compares with the symmetric design as shown before.

In conclusion, a rate-equation model is developed, with the consideration of dielectric Bragg reflectors and carrier induced index change inside the active layer, to analyze the polarization bistability of VCL's under external optical injection. It is shown that all-optical switching and memory operation can be achieved in VCL's by external optical injection, however, devices with suitable design of surface coating and Bragg reflectors are required.

References

[1] Y. Mori,'Dynamic properties of transverse magnetic wave injected semiconductor lasers', IEEE J. Quantum Electron., vol. 27, pp. 1415-1421, 1991.

[2] H. Kawaguchi,'Absorptive and dispersive bistability in semiconductor injection lasers', Optical & Quantum Electronics, Vol. 19, pp. S1-S36, 1987.