Polarization switching control in vertical-cavity surface-emitting lasers

Timothy H. Russell and Tom D. Milster

University of Arizona, Optical Sciences Center, Tuscon, Arizona 85726

(Received 19 August 1996; accepted for publication 17 March 1997)

Orthogonal polarizations within vertical-cavity surface-emitting lasers (VCSELs) lase at slightly different wavelengths. We describe the use of optical feedback to confine polarization variations to reproducible injection currents. An external cavity is used to select specific wavelengths that reflect back into the VCSEL, hence, changing the cavity Q for the different polarization states. With this control, we can change the polarization state of the laser output.

Recent literature on vertical-cavity surface-emitting lasers (VCSELs) indicates that they exhibit good optical characteristics. For example, VCSEL beams are not astigmatic, which allows for easy reimaging to diffraction limited spots. Due to the extremely short cavity lengths, the number of longitudinal modes that can be supported is very small, and often only a single mode will lase. These characteristics make VCSELs very desirable in many applications including optical communications, optical interconnects, optical processing, optical neutral networks, etc.

An aspect of VCSELs that sets them apart from edge-emitting semiconductor lasers is that no selection rule controlling the polarization of the optical output beam has been observed. This creates interesting effects that may be used for optical switching. In some VCSELs, the output polarization is observed to switch orientation at injection currents that vary from device to device. Control of this switching has been the subject of several papers. Electrically induced polarization switching at rates up to 50 MHz have also been observed by sinusoidally varying the injection current near a polarization transition. Switching between polarization states in polarization bistable VCSELs has also been reported by injecting light of the desired polarization into the cavity. Once the polarization state begins to lase, the injected light is no longer needed, and the VCSEL will continue to lase in the same orientation as the injected light. These two examples, however, require the use of preexisting polarization transition regions. Some VCSELs do not have transition regions, and for those that do, the injection currents where the polarization transitions occur vary substantially. In this letter, a method that allows for some control of the injection current at which partial polarization switching takes place is introduced.

When there is no gain or cavity anisotropy built into the laser, the mechanism that determines the dominant polarization orientation is unknown. In most cases, the polarization of these lasers is aligned with or normal to the (011) direction in the crystal. Polarization switching takes place between these two orientations. Stress in the laser also affects the polarization orientation. Gain is higher when the electric field is in the direction of the stress. The crystal orientation and stress direction compete to define the final orientation of the electric field. Although a laser may have no anisotropies built into it, gain saturation, anisotropic near-field patterns, and variations in the stress from the injection current are some properties that could account for polarization switching. Unfortunately, these are not well controlled in VCSELs; thus, the injection current at which switching occurs is randomly distributed.

In this letter, a different method is proposed to control polarization switching. As observed in Refs. 7 and 10, a doublet of orthogonally polarized beams is present in the light emitted from VCSELs. If the light is emitted in the z direction, the laser can be adjusted such that doublet orientations align with the x and y axes of the optical system. Since light polarized in the x and y orientations have slightly different frequencies, it should be possible to use an external mirror such that the second reflector within the VCSEL and the external mirror define a Fabry–Perot cavity that has a wavelength-selective reflectivity. A high transmission occurs only at specific wavelengths. This high transmission out of one side of the VCSEL spoils the Q of the cavity for that wavelength. Since the wavelength of the two polarizations is slightly different, if the cavity is spoiled for the y polarization and the Fabry–Perot linewidth is small enough, the x polarization will see a very high reflectivity off the Fabry–Perot and have a high cavity Q. The effect will decrease the power lasing in the y polarization and increase the power lasing in the x polarization.

The spectral width of a Fabry–Perot cavity is given by

$$\Delta \nu = \frac{c \cdot (1 - \sqrt{R_1 \cdot R_2})}{2 \cdot \pi \cdot n \cdot L \cdot (R_1 - R_2)^{1/4}},$$

(1)

where $c = 3 \times 10^8$ m/s, $L$ is the length of the cavity, $n$ is the index of refraction of the cavity, and $R_1$ and $R_2$ are the mirror reflectivities. As long as $\Delta \nu$ is small enough to resolve the polarization doublet, optical switching control should be possible in VCSELs. References 7 and 10 recorded doublet separations of $<0.2$ Å and $\approx 0.3$ Å, respectively. Assuming mirror reflectivities of 99% and 87%, wavelength operation of 850 nm, index of refraction 1, and a doublet separation of 0.4 Å, the external cavity length must be greater than 0.29 mm to resolve the doublet and obtain strong optical switching. (Both VCSEL distributed Bragg reflectors have high reflectivities $\approx 99\%$, but, even so, the required cavity length to resolve the doublet is longer than the VCSEL cavity length, which is one of the reasons that the VCSEL laser cavity supports both modes.)

In our experiment, a VCSEL was placed so that the emitted light propagated in the z direction and was aligned...