Design and analysis of optically pumped semiconductor VECSEL with ANECz optical control layer

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Through the reversible isomerization of trans-cis-trans under the linear polarization light, the molecules of azo materials have the same tropism which is vertical to the polarization of light. This means that azo materials have photo-induced birefringence which is related to optical power and polarization angle of the light. Based on the photo-induced birefringence of azo materials, we design a new type of optically pumped semiconductor vertical external cavity surface emitting laser (OPS-VECSEL) which can control the polarization and frequency of the ejection laser. The functional molecules of azo materials are [3-azo-(4'nitro)]-(9-ethyl)-carbazole (ANECz).

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Recently, polymer lasing has become more and more attractive due to its academic interest and potential application in modern display technology and integrated optics[1−6]. When the azo materials are under the polarization of light, they present macroscopic anisotropy, which means that they have photo-induced birefringence[7−13]. The molecules of azo materials have the same tropism which is vertical to the polarization of light. The value of birefringence is related to optical power and polarization angle of the light, therefore, we can change the birefringence of azo materials through modifying the status of light. Based on this characteristic, we design a new type optically pumped semiconductor vertical external cavity surface emitting laser (OPS-VECSEL) which can control the polarization and frequency of the ejection laser by using the azo materials of [3-azo-(4'nitro)]-(9-ethyl)-carbazole (ANECz).

The structure of the OPS-VECSEL with ANECz is shown in Fig. 1. Between two distributed Bragg reflector (DBR) layers actings as reflection layer and ejection mirror respectively, the active layer and the ANECz optical control layer are arranged. Ordinary OPS-VECSEL has a structure of single DBR, which means that one end uses an ejection mirror with reflection ability and the other end uses the DBR. We use asymmetry double DBR layers in our ANECz OPS-VECSEL. The growing sequence is H···L···H (H and L represent high- and low-index materials, respectively), and the central wavelength is 600 nm.

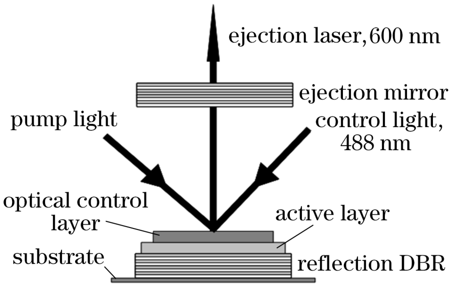

Fig. 1. Schematic of the OPS-VECSEL with ANECz optical control layer.

Different needs make us select different azo materials. The absorption band is 200 − 520 nm, and there is the strong absorption at 488 nm. We just consider the strong absorption at 488 nm for simplification, so we select ANECz as the control layer and use 488-nm light as control light. The birefringence value of the optical control layer will change when changing the intensity and polarization. In our model, we use the Ar^+ laser as control light, whose intensity is about 60 mW/cm^2. In addition, we also need to control the polarization of control light with a polarizer. For the active layer, according to the previous research[5,6], PVK:Alq_3:DCM mixture is used as the active medium, Ar^+ laser at the wavelength of 514.5 nm is used as the pump laser, and the incident angle is 45°.

A perfect VECSEL can be treated as an isotropy medium. The fundamental mode in the resonant cavity has two orthogonal modes called p- and s-polarization components. The optical admittance η is shown as

$$\eta = \begin{cases} N/\cos\theta & \text{for p polarization} \\ N\cos\theta & \text{for s polarization} \end{cases}, \tag{1}$$

where N is the complex refractive index, θ is the refractive angle.

Through the reversible isomerization of trans-cis-trans under the linear polarization light, the molecules of azo materials have the same tropism which is vertical to the polarization of light. This means that azo materials will generate birefringence. There are an effective index $n_{/\!/}$ which is parallel to the polarization of pumping light and an effective index $n_\perp$ which is vertical to the polarization of pumping light. Under this situation, they are no longer equal. The difference between them is the birefringence value,

$$\Delta n = \left| n_{/\!/} - n_\perp \right|. \tag{2}$$

Under the linear polarization light, birefringence is produced. The isotropy medium now has two different optical axes $\vec{n}_{/\!/}$ and $\vec{n}_{\perp}$. Due to the impact of birefringence, the complex indices of s- and p-polarization components are different,

$$N_{\rm p} = n_{\rm p} + i\left(\frac{-g_{\rm p}}{2k_0} - \kappa_{\rm p}\right), \tag{3}$$

$$N_{\rm s} = (n_{\rm s} + \Delta n) + i\left(\frac{-g_{\rm s}}{2k_0} - \kappa_{\rm s}\right), \tag{4}$$

where $n_{\rm s}$ and $n_{\rm p}$ are real indices of s- and p-polarization components, Δn is birefringence valve, $g_{\rm s}$ and $g_{\rm p}$ are gain coefficients of s- and p-polarization components, $\kappa_{\rm s}$ and $\kappa_{\rm p}$ are extinction coefficients of s- and p-polarization components, k_0 is the wave vector in vacuum. The optical admittances of s- and p-polarization components are

$$\begin{cases} \eta_{\rm p} = N_{\rm p}/\cos\theta \\ \eta_{\rm s} = N_{\rm s}\cos\theta \end{cases} \qquad N_{\rm p} \neq N_{\rm s}. \tag{5}$$

According to the transfer matrix method, combining Eqs. (3), (4), and (5), we can get the transmission spectrum of OPS-VECSEL considering the impact of birefringence.

For simplification, we ignore the impact of radiation angle. Then the impact of photo-induced birefringence of ANECz on VECSEL with asymmetry DBR structure will be analyzed through analyzing the transmission spectrum of the resonator.

We simulate the transmission spectrum of the whole resonator, as shown in Fig. 2. The birefringence produced by ANECz makes the degenerated p- and s-polarization components not longer in degeneration. ANECz changes the degenerated modes. The larger birefringence does not make the transmission spectrum of p-polarization component change, but make the transmission spectrum of s-polarization component shift far away from 600 nm and the transmission rate become bigger than that of p-polarization component. If we just consider the ejection laser at 600 nm, bigger birefringence value ($\Delta n = 0.1$) makes the ejection laser only have p-polarization component. If we consider the ejection laser at 620 nm, we can get single polarization ejection laser which only has s-polarization component. So we conclude that the photo-induced birefringence effect of ANECz helps us to control the polarization of the ejection laser. The bigger the birefringence value is, the more obvious the effect is. Therefore we can use the optical control layer of ANECz materials to control the polarization of the OPS-VECSEL ejection laser.

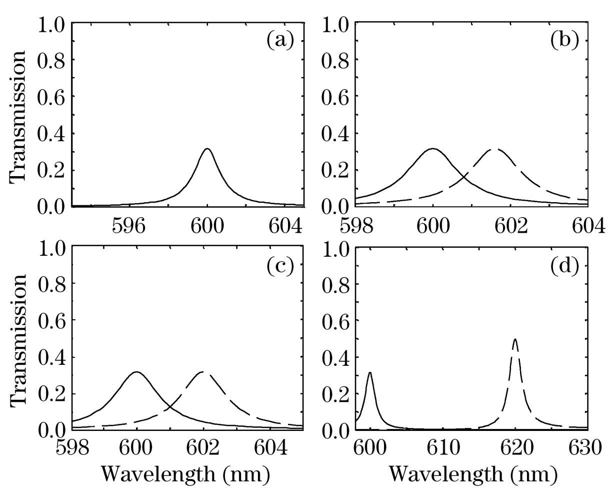

Fig. 2. Transmission spectra of different birefringence values Δn with double DBR structure. Dashed lines represent the s-polarization component, solid lines stand for the p-polarization component. (a) $\Delta n = 0$; (b) $\Delta n = 0.008$; (c) $\Delta n = 0.01$; (d) $\Delta n = 0.1$.

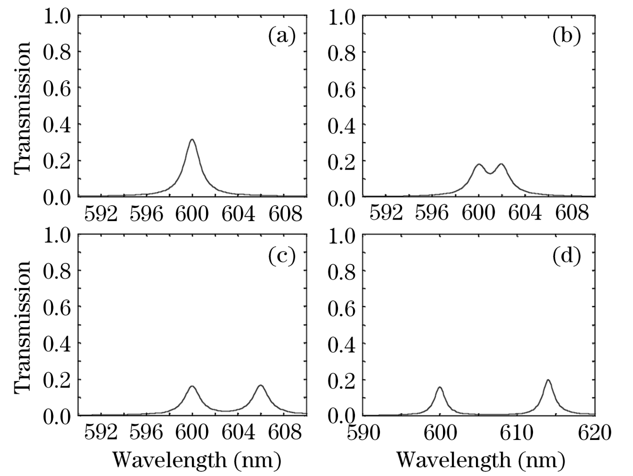

Fig. 3. Different birefringence transmission spectra of double DBR structures. (a) $\Delta n = 0$; (b) $\Delta n = 0.01$; (c) $\Delta n = 0.03$; (d) $\Delta n = 0.07$.

When we use ANECz as the optical control layer, the ejection laser has two central wavelengths, as shown in Fig. 3. When the birefringence value is zero, only 600-nm laser exists. The new wavelength emerges and moves to long-wavelength side with the increase of the birefringence value, which means through changing the birefringence value, we can get new laser besides 600-nm laser. Therefore, the optical control layer of ANECz acts as the selector of laser wavelength when the polarization components are not considered.

The birefringence value changes when ANECz is illuminated under 488-nm control light. We can tune the birefringence value by changing the polarization and intensity of the control light. Due to the changes of birefringence value, the wavelength and polarization of the ejection laser also change. Therefore we conclude that, theoretically, OPS-VECSEL with ANECz optical control layer is a new type of polarization control and wavelength tunable laser.

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