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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 will generate 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).

The structure of the OPS-VECSEL with ANECz is shown in Fig. 1. Between two distributed Bragg reflector (DBR) layers acting as reflection layer and ejection mirror respectively, the active layer and the ANECz optical control layer are arranged. Ordinary OPS-VECSEL has two orthogonal modes called p- and s-polarization. In our model, we use the Ar\textsuperscript{+} laser as control light, whose intensity is about 60 mW/cm\textsuperscript{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\textsuperscript{[5,6]}, PVK:Alq\textsubscript{3}:DCM mixture is used as the active medium, Ar\textsuperscript{+} 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 $\eta$ is shown as

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

Fig. 1. Schematic of the OPS-VECSEL with ANECz optical control layer.
Under the linear polarization light, birefringence is produced. The isotropy medium now has two different optical axes \( \vec{n}_x \) and \( \vec{n}_z \). Due to the impact of birefringence, the complex indices of s- and p-polarization components are different,

\[
N_p = n_p + i \left( \frac{-g_p}{2k_0} - \kappa_p \right),
\]

\[
N_s = (n_s + \Delta n) + i \left( \frac{-g_s}{2k_0} - \kappa_s \right),
\]

where \( n_s \) and \( n_p \) are real indices of s- and p-polarization components, \( \Delta n \) is birefringence valve, \( g_s \) and \( g_p \) are gain coefficients of s- and p-polarization components, \( \kappa_s \) and \( \kappa_p \) 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

\[
\begin{align*}
\eta_p &= N_p / \cos \theta \quad N_p \neq N_s, \\
\eta_s &= N_s / \cos \theta.
\end{align*}
\]

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.

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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