High-Contrast Grating Spatial Mode Filter for Widely Tunable Vertical Surface Emitting Laser

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Abstract: We present the highly angular dependent High-Contrast Grating (HCG) mirror functioning as a spatial mode filter for widely tunable single-mode VCSELs. The incident angular dependence of GaAlAs/air HCG mirror was calculated for TE mode light using Rigorous Coupled-wave Analysis (RCWA). We are able to use the angular dependence of HCG for the transverse-mode control of widely tunable VCSELs by filtering out high-order transverse-modes. The modeling results show HCG offers the spatial mode filtering for a wide wavelength range over 60 nm at 980 nm band. This result may lead to widely tunable single transverse mode VCSELs with high-output power.

Vertical Cavity Surface Emitting Lasers (VCSELs) are key devices for optical communications and optical sensors. They offer low threshold operations and hence low power consumptions with help of their small active region. However their single-mode output power is limited by their large thermal resistance caused by the small cavity volume. Expanding active region enables us to improve manufacturing tolerance and to increase single-mode output power. A key challenge is how to control the transverse mode for single-mode operations. There have been various reports on the transverse-mode control, which include surface relief structures, metal apertures, multi-oxide layers and so on[1-3]. Their basic common idea is to use spatial mode filtering with adding excess losses for high-order modes. We proposed and demonstrated the engineered angular dependence[4] of high contrast grating (HCG)[5, 6] for the transverse-mode control of VCSELs[7, 8]. On the other hand, widely tunable VCSELs are attracting much attention for use in Optical Coherent Tomography (OCT). There is a strong demand to boost the single-mode output power over a few tens mW.

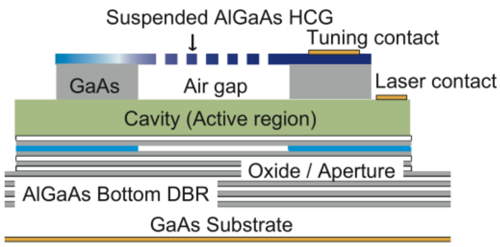

Fig.1 Device structure of the HCG MEMS VCSEL

In this paper, we present the modeling of highly angular dependent HCG functioning as a spatial mode filter in broad wavelength range. The result shows a possibility of widely tunable single-mode VCSELs with high output power.

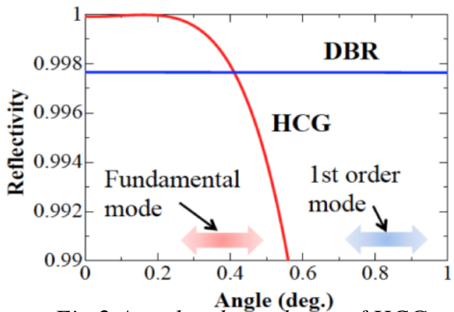

Fig.2 Angular dependence of HCG and DBR mirror

Figure 1 shows the schematic structure of a tunable VCSEL with a membrane HCG mirror. The basic idea for the transverse mode control of HCG VCSELs is illustrated in Fig. 2. The transverse spatial frequency and propagation angle of each transverse mode are different. A fundamental mode has the smallest propagation angle and high-order modes show larger angles. Thus we are able to select only a fundamental mode using the highly angular dependent reflectivity of HCG. This advantage is to avoid all the higher-order modes. This would come from the spatial frequency filtering thanks to the highly angular dependence.

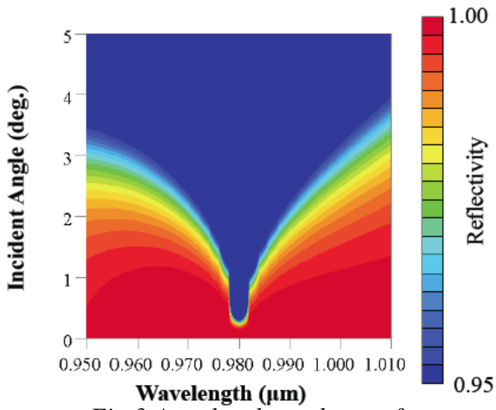

Fig.3 Angular dependence of reflectivity versus wavelength

We calculated the reflectivity of HCG using the RCWA method. The high-index material of HCG is $Al_{0.65}Ga_{0.35}As$ and surrounded by air. The grating parameters are grating thickness, period and duty cycle. Figure 3 shows the incident angle dependence of reflectivity versus wavelength. We see the large angular dependence, but it is dependent on the operating wavelength. We carried out the optimization of grating parameters for a wide wavelength range. We define a single-transverse mode condition when the difference in reflectivity between the fundamental transverse mode and the 1st order mode is >0.5%. We found the grating thickness is an important parameter for expanding a wavelength region. By calculating the propagation angle and reflectivity at incident angle, we obtain the maximum active region size for single transverse mode operation as shown in Fig. 4(a). Additionally, a high reflectivity is needed for low threshold operations. Figure 4(b) shows the reflectivity mapping for the normal incidence as function of wavelength. From these results, we show the maximum active region size that meets >99% of reflectivity as shown in Fig. 4(c). The orange and red areas in Fig. 4(c) indicate the capability of single-mode active region size of >20μm. The result indicates a wide wavelength range of over 60nm for single-transverse-mode operations.

In conclusion, we present the engineered angular dependence of HCG for widely tunable single-mode VCSELs. The high angular dependence of HCG enables us to expand an active region of over 20 μm, which is several times larger than that of conventional single-mode VCSELs. We expect a high single-mode output power of a few tens mW and wide wavelength tunability at the same time. This could make great contributions for bio-medical applications of VCSELs such as OCT.

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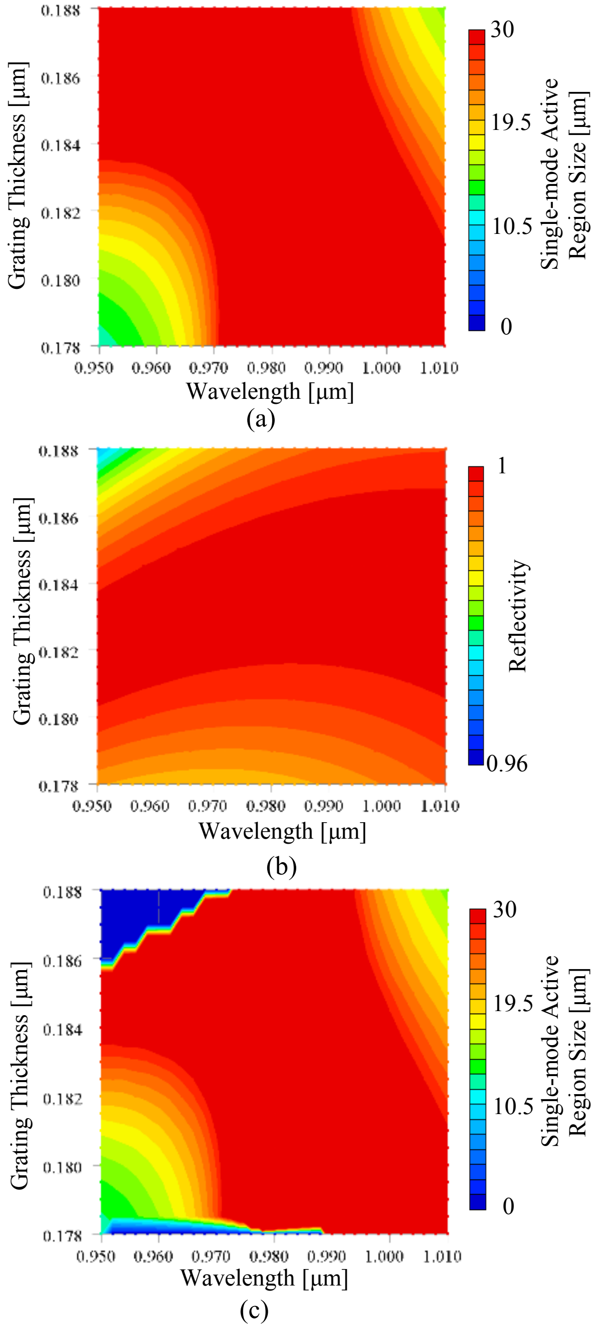

Fig.4: (a)Single-mode active region size (b)Reflectivity to normal incidence (c)Single-mode active region size that meets high reflectivity to normal incidence

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