A New Design Method for External Cavity Structure of Tunable Semiconductor Laser

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Abstract—**It presents a new method that makes use of grating light valve (GLV) in order to adjust minutely output wave-packet in grating external-cavity semiconductor laser. This structure in tunable semiconductor laser based on grating light valve forms grating light valve and blazed grating into confocal structure, Wave-packet selected can backtrack and be exported in the end by oscillating movement in resonant cavity. The tunable external-cavity semiconductor laser based on grating light valve can select at will output or filtrated corresponding wave-packet magnitude. This kind of tunable external-cavity semiconductor laser using characteristic of grating light valve can achieve minutely tuning of output wave-packet and reduce mechanical tuning difficulty.**

Keywords-grating light valve (GLV); tunable; semiconductor laser; blazed grating

I. INTRODUCTION

Laser diode（LD） has outstanding features including high spectrum purity, compact structure, low cost, good reliability, convenient operation and being easy to integrate. Since 1990s, it is widely used in fiber optic communication [1] [2], optical heterodyne sensing, high-resolution spectrum measurement, biological medicine and many other fields. However, general laser diode has its deficiency that the spectrum line is wide and the frequency is unstable. So the tunable external-cavity LD is developed to feed the need for light sources with good monochromaticity and tunable wavelength. In 1964, J.W.Crowe and R.M.CraigJr founded the external cavity theory [3]. And in 1980, R.Lang and K.Kobayashi firstly applied external cavity feedback technology, which is used on dye laser before, to laser diode and successfully realized narrowing linewidth and wavelength tuning [4]. Since then reports about theory, experiments, application of laser diode with external feedback sprang up continuously.

Grating is a kind of dispersion element with high-resolution that can be used as optical feedback element to form external cavity to perform the narrowing linewidth and wavelength tuning of laser diode. Grating structures generally being used are type littrow and type littman. While both these two structures increase the requirement for machinery and lower the accuracy of wavelength selection, because they both contain rotating system. In this paper, we project a new method of external cavity tunable LD based on GLV that can avoid the questions mentioned above.

II. GRATING EXTERNAL CAVITY TUNABLE LD AND ITS DEFECTS [5]

The light path arrangement of grating external cavity tunable LD mainly takes the two structures: littrow and littman. The former one is a kind of rotating grating structure, as Fig.1 shows. Beam produced by laser diode is aligned by short focal length compound lens and then incident on reflection gratings. Adjust reflection gratings to feedback primary reflection beam aligned by collimation lens to laser diode to oscillate. After repeating this several times, stable optical oscillation will form, thereby producing single-mode and stable lasers. Zero-order reflection beam provides output lasers. Adjust the angle of gratings through piezoceramics to make beams with different wavelength oscillate in external cavity to ultimately generate single-mode and stable lasers with different frequency. Littrow ECDLs has simple structures and it is easy to debug. But the direction of output lasers changes along with rotation of gratings during tuning process, which may bring inconvenient to the practical applications. In addition, the accuracy of tuning is limited because grating is artificially rotated by transmission device, which purely belongs to mechanical methods.

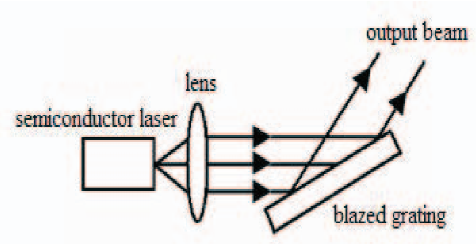

Figure 1. Littrow model structure sketch map of grating external cavity LD

Litterman structure makes use of coordination between fixed grating and rotating reflection mirror, as Fig2 shows. The external cavity of laser consists of laser diode, collimation lens, blazed grating and reflecting mirror [6]. The output beams of LD turn into parallel ones after being aligned by short focal lens and incident on the grating. Through diffraction-gratings, the zero-order light emits and the primary diffraction beam impinges on a high-reflection mirror. Adjust the angle of reflecting mirror to make its normal direction the same axis with primary light. Then the primary diffraction beam returns according to original path. After diffraction, it goes back to active region to interact with light field in that region. The beam with λ_0 wavelength can decrease its loss and lower its threshold at λ_0 to gain oscillation edge when it is sent back to active region by grating while other wavelengths would be suppressed since they face greater loss. But it is inappropriate for taking this kind of structure for practical application, because it has big volume and difficult beam alignment. Especially its design of mechanical tuning has hysteresis and engenders slight abrasion, which can affect long-term reliability required by optical communication application. Besides, by using the rotation system of reflection mirror, it is indispensable to control this system by electricity to increase the resolution of wavelengths, which also inevitably raises the cost. And the system is relatively sensitive to vibration from outside because of unfixed reflection mirror. This kind of vibration results in changes of cavity length, then causes external cavity vertical film to shift.

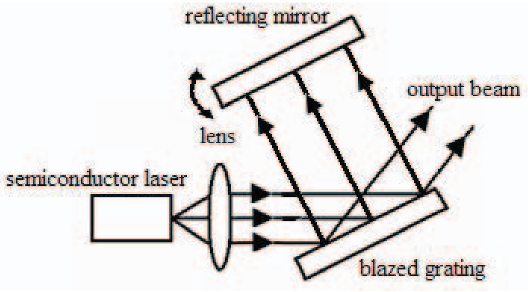

Figure 2. Littman model structure sketch map of grating external cavity LD

III. USING GLV TO IMPLEMENT WAVELENGTH TUNING OF EXTERNAL CAVITY LD

A. Principle of GLV technology [7] [8]

Grating light valve (GLV) is a new reflective phase grating micromodule using MEMS technique, conventional material CMOS and equipment processing and moulding. GLV technology is invented by David Bloom and his group at Stanford University in 1992. Compared with traditional grating, GLV has great performances including high-reliability, high-repetitiveness, low-cost, fast respondence and being easy to integrate with CMOS logical circuit. After being published, GLV has been successfully applied to many fields like high-speed optical attenuator, optical switch, direct platemaking system, ultraviolet platemaking system, infrared communication product, HDTV display, film projector and display equipment of flight simulating training [9] [10]. GLV is a kind of light reflection component, consisting of strips of banding reflectors. These reflectors move up and down subjected to electrostatic force, making GLV form a diffraction grating and work on on-state and off-state. The principle of GLV is based on the reflex, diffraction and interference effects of light: GLV device is made on silicon wafers by MEMS technique. Its basic frame is built by several units consisting of even-number parallel strip structures, as Fig3 shows. The strip structure can be adjusted according to design requirements. The typical design unit shown in Fig3 consists of six strip structures with each 3μm width, 100μm length and about 100nm thick. Each terminal of the strip structure has one support point while the middle suspends above a very thin air layer (about 650nm thick). The strip structure is made of Si3N4 which provides relatively high tension and strong durability. Its surface is aluminized to improve reflectivity and conductivity. The underlying surface is taken for common electrode. In these six banding structures, imposing a certain voltage to the three movable strips can make them move up and down subjected to electrostatic force. Without voltage, these movable strips would not move but stay tightened so that a flat surface forms in the middle of the whole unit, making GLV units in perfect reflecting state. While when we impose a voltage between movable strips and substrate, electrostatic attraction makes the three alternated movable strips move down and form a phase grating on the surface, as Fig4 shows. At the moment, GLV units are in diffraction state. In this condition, the optical waves reflected by fixed strips and movable strips produce a phase difference. The grating generates diffraction peak at angle θ :

$$\theta_m = \arcsin(\frac{m\lambda}{\Lambda}) \qquad (1)$$

Λ : interval between each two of movable strips
m: diffraction order
λ : wavelength

When the depth δ that movable strips go down reaches one quarter of the wavelength of incident light, namely $\delta = \lambda / 4$, the luminous intensity of diffraction light can meet its maximum value. The relation between luminous intensity of primary diffraction light and grating depth δ is:

$$I_1 = I_m \sin^2(\frac{2\pi\delta}{\lambda}) \qquad (2)$$

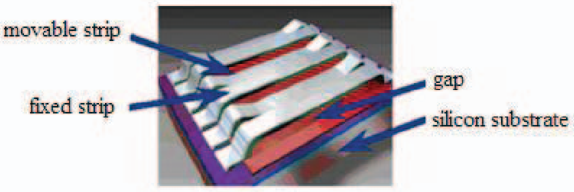

Figure 3. Basic GLV structure

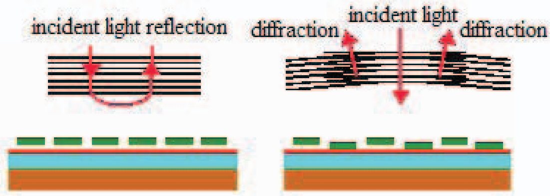

Figure 4. Reflective state and diffractive state of grating light valve

B. Implementing precision tuning of external cavity LD by GLV

ITU-T standard sets highly strict rules to carrier wavelength of optical signals applied to DWDM. Wavelength intervals are all very small. Nowadays the practical wavelength interval is 0.8nm and it will be diminished to 0.4nm or even smaller to 0.2nm. So it is required that the wavelength of laser (mainly refers to laser diode) should not only meet ITU-T standard, but also be very stable. Based on the analysis mentioned above, we project a new method that implements precision tuning of external cavity LD by using GLV. Fig5 shows its principle. This kind of structure is an improvement based on Littman grating external cavity tuning structure. It replaces the reflector rotating structure with a GLV array. Its mechanics is as follows. The beams generated by LD incident on the surface of the blazed grating after being expanded and aligned by convex lens. The blazed grating is a dispersion element that can make incident light emit from different angles. Then different wavelengths dispersed by the blazed grating go through lens and focus on the surface of GLV. Beams with different central wavelengths shoot on different GLV work units. It is very convenient to control each kind of beams because every work unit in GLV can be operated independently. For instance, if one certain unit is not electrified, then it is a plane mirror, which can force the beam with corresponding wavelength to be reflected to original path and oscillate in the external cavity till amplifier output; while if one certain unit is imposed a voltage signal, then it is in diffraction grating state, which prevents the beam with corresponding wavelength from being reflected and oscillating, thus consuming this part of energy.

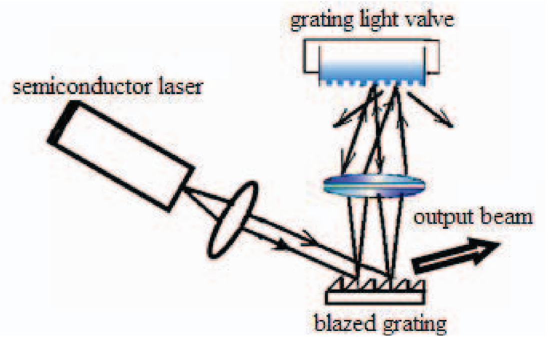

Figure 5. Structure sketch map of grating external cavity LD based on GLV

In this kind of structure, the blazed grating, condensing lens and the GLV array form a typical confocal frame, which is the key to keep corresponding beam retracing original path when wavelength selection is processing in LD. The blazed grating is located in the front focal plane of lens while the GLV array is in the back focal plane so that beams with different wavelengths can emit in parallel from different angles after incident light being dispersed by the blazed grating and then focus on the surface of GLV. Because the axis of the convergent beam is perpendicular to GLV, when one certain GLV unit is in plane mirror state, the corresponding beam returns in original path after reflection and becomes the chosen beam. On the contrary, when one certain GLV unit is in diffraction grating state, diffraction appears in incident light to prevent beam from returning and filter it. This method can freely control the quantity of beams which to be outputted or filtered because each of the work unit in GLV array can be operated independently.

IV. CONCLUSION

In this paper, we project a new method that uses GLV to implement accurate wavelength tuning of grating external cavity LD. The structure of tunable external cavity LD based on GLV makes GLV and the blazed grating form confocal frame, which is good for allowing the chosen beam to retrace its original path, oscillate in resonant cavity and eventually output. This design is directed against the deficiency of the former one including low tuning speed, complicated structure and big volume by fully utilizing the advantages of GLV like small volume, easy operation and high-speed. The structure based on GLV can freely control the quantity of beams which to be outputted or filtered. It effectively improves the tuning accuracy of output lasers by utilization of GLV features and has extremely high precision, reliability and stability. Meanwhile, it reduces the mechanical difficulty of tuning.

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