MEMS TUNING MECHANISM FOR ELIMINATING MODE HOPPING PROBLEM IN EXTERNAL-CAVITY LASERS

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ABSTRACT

This paper presents a tuning mechanism to provide an adjustable virtual pivot for MEMS tunable lasers, which eliminates the mode hopping problem associated with conventional Littrow lasers. The key idea is to attach the two ends of the blazed grating to two separate translational actuators. The relative displacements of the actuators can be used to translate and/or rotate the blazed grating in a controllable manner. As a result, the wavelength can be continuously tuned ideally over an unlimited range through a simultaneous sweep of the grating angle and cavity length. In the experiments, a MEMS Littrow laser is fabricated by the DRIE process on the SOI wafer and is integrated onto a single chip with the size of 3mm × 3mm. It achieves a wide tuning range of 53.2nm thanks to the introduction of new tuning mechanism and a 3D optical coupling system.

1. INTRODUCTION

Tunable lasers with broad tuning range have been explored extensively due to their importance for many applications, such as optical communications and spectroscopy. One of the advantages of the use of tunable lasers is that it promises drastic cost saving. Also, the tunable lasers could ultimately lead to increased network intelligence, functionality, and efficiency. Among the various technological options, external cavity tunable laser (ECTL) has attracted significant interests because of its inherent potential to provide continuous tuning over a wide range, high output power and excellent wavelength accuracy. The most common configurations for the external-cavity lasers are Littrow [1] and Littman [2], and traditionally, both are constructed by combining separate active and passive components. In these two configurations, the wavelength tuning is achieved by the combination of the translation and rotation of the grating. However, the deployment of ECTLs has been somewhat hampered due to the complicated optical assemblies, low mechanical stability and large size. The rapid development of microelectromechanical systems (MEMS) technology has opened a new window for the miniaturization of the lasers, and made it possible to integrate various components into a single chip [3-8]. An early work demonstrated the MEMS tunable laser using bulk micromachining and nickel electroplating [3]. A continuously tunable laser was later demonstrated in a Littman configuration [4], in which a special MEMS actuator was used to carry and rotate the mirror for continuous tuning. In fact, for the MEMS ECTLs, the Littrow configuration may be preferable since the Littman architecture needs a well-collimated beam shooting on the blazed grating at a large angle. Furthermore, the Littman configuration requires a double pass through the grating, which may result in low diffraction efficiency and increase the difficulty of optical coupling within the external cavity.

Although a fixed pivot for grating rotation can provide a continuous tuning in the Littrow configuration, the tuning range is limited (typically < 30 nm [9]). Moreover, the fixed pivot design could lead to mode hopping problem since the cavity supports discrete longitudinal modes [9-12]. According to the analysis of [9], a moving pivot is required to obtain a mode-hop-free Littrow laser.

In this paper, we propose a tuning mechanism for the Littrow configuration, which has a potential to simultaneously achieve rapid tuning rate and wide tuning range without mode hopping. Section 2 will cover the theoretical study of the Littrow laser and the concept of the proposed tuning mechanism, followed by the fabricated device and experimental results in Section 3.

2. THEORY AND DESIGN

A schematic of the typical configuration of Littrow tunable laser together with the concept of tuning is illustrated in Fig. 1 (a). It comprises a semiconductor gain chip (with one end high-reflection (HR) coated and the other end anti-reflection (AR)), a rod lens, a microlens and a blazed grating. In this case, the external cavity consists of the two collimating lenses and a blazed grating. In the tunable laser, the total laser cavity length (including the external cavity length) and the blazed grating angle both add their requirements to the oscillating wavelength. For a continuous wavelength tuning, the two requirements should always match with each other as given by

\[ N_0 \lambda_c = 2 L_c \]  \( \text{(1)} \)

\[ m_0 \lambda_g = 2 p_0 \sin \phi \]  \( \text{(2)} \)

where \( \lambda_c \) and \( \lambda_g \) represent the wavelength determined by the laser cavity and the grating, respectively (subscript \( c \) for cavity and \( g \) for grating). \( N_0 \) indicates cavity mode number, \( m_0 \) is grating diffraction order, \( p_0 \) is grating period, \( \phi \) stands for the diffraction angle, and \( L_c \) is the total effective optical cavity length. In order to tune the wavelength, the
Grating arm is rotated about the virtual pivot (as shown in Fig. 1(a)), therefore \( L_c \) varies with \( \phi \).

According to Eq. (1) and (2), it has

\[
L_c = \left( \frac{N_0 p_0}{m_0} \right) \sin \phi
\]

The position of the virtual pivot can be further derived to be

\[
x = \left( \frac{N_0 p_0}{m_0} \right) \cos \phi \sin \phi
\]

\[
y = \left( \frac{N_0 p_0}{m_0} \right) \cos \phi
\]

-20
-10
0
10
20

Virtual pivot shift (%)

Change of grating angle (deg.)

Figure 1: Requirement to the pivot for mode-hopping-free in the Littrow laser. (a) Schematic diagram of the Littrow laser; (b) the shift of pivot position during the wavelength tuning.

According to Eqs. (4) and (5), a continuous tunability without longitudinal mode hopping can be achieved with a movable pivot since the position of the pivot will be shifted with the variation of the grating angle. However, in conventional designs that use the fixed pivot, such condition cannot always be matched and thus causes mode hopping when the rotation angle goes larger. As a result, the wavelength tuning range is limited, typically from several to 30 nm [9].

Analytical results of the virtual pivot shift in response to the grating angle change are shown in Fig. 1(b). The relevant parameters will be defined in the next section. It shows that for a grating angle change of ±3 degree, the pivot should be shifted from -20% to 17.4% in the \( x \) direction. On the other hand, the same rotation requires the pivot has a shift from -9.4% to 11.6% in the \( y \) direction. Clearly, a movable pivot is required. To address such need, we propose a new tuning mechanism to provide an adjustable virtual pivot.

The concept of the proposed tuning method is shown schematically in Fig. 2. In this case, the translation and rotation of the blazed grating can be controlled separately by properly shift the two joints (A and B) driven by two comb-driving actuators. In principle, when the two soft joints move in opposite directions, or they shift in the same direction but with different distances, a grating rotation occurs as shown in Fig. 2(a). A translation of the grating could happen when the two joints move in the same direction and at the same rate as well as shown in Fig. 2(b). Therefore, the independent control of the movement provides a simultaneous change of the cavity length and the grating incidence angle. Thus, it is easy to obtain any relationship of grating angle and cavity length, which offers a fundamental way to eliminate the mode hopping problem. Moreover, it is convenient to adjust the initial condition of the tunable lasers so as to tolerate the discrepancy of the gain chip size.

Figure 2: Independent rotation and displacement of the grating to obtain a movable virtual pivot. (a) Rotation of the grating; and (b) the displacement of the grating.
3. EXPERIMENTAL RESULTS

Following the design, a MEMS tunable laser has been fabricated and integrated. An overview of the packaged device is shown in Fig. 3, together with the close-ups of the blazed grating and the soft joint. The MEMS components, (including a blazed grating, a microlens, two bidirectional comb drive actuators), are all fabricated on an 8” silicon-on-insulator wafer (structure layer 75 μm thick) by the deep reactive ion etching process. Two electrostatic comb drive actuators are used to translate and rotate the blazed grating for wavelength tuning. The microlens has a focus length of 150 μm, which can collimate the output beam from the AR-coated facet onto the diffraction grating in the horizontal direction. Furthermore, to improve the optical coupling, a rod lens is introduced to collimate the light in the vertical direction, with a focus length of 98 μm [13]. To improve the reflectivity, the grating is coated with 0.5 μm thickness of aluminum. The grating has a period of 5.48 μm at a designed blazed angle of 45°. The soft joint is used to connect the grating to the comb-drive actuators.

To monitor the optical coupling in the external cavity, the beam propagation of the MEMS tunable laser is visualized by an infrared CCD camera under a microscope as shown in Fig. 4. Emission from the gain chip firstly passes through the rod lens and the micro lens. Then, the transmitted beam is diffracted on the blazed grating. The radiation of the laser modes is collimated by these two lenses and directed back to the laser chip. Bright light spots can be observed on both sides of the rod lens due to the scattering/reflection on its curved surface. The scattering also happens at the edge of the micro lens, but it is really weak when observed from the top since the etched sidewall of the microlens has good verticality and smoothness. Obviously, the light scattered by the grating is very bright. It indicates that the combination of the rod lens and microlens collimates the laser beam effectively. It is believed that such optical combination could improve the optical coupling efficiency and the laser output quality.

Measurements results of the electro-mechanical properties of the actuators are presented in Fig. 5. Either of the soft joints (A or B as shown in Fig. 1) is the connection at the cross of the grating and the beam of the actuator. From Fig. 5 it can be seen that the displacement of the soft joints is not obvious when the applied voltage is below 6 V. Then it is increased gradually with higher voltage, and rises to 36 μm with the increase of the voltage to 33 V following a quadratic relationship. At the voltage of 30 V, both soft joints are displaced by 30 μm.

The relationship between the grating angle change and the displacements of two soft joints is shown in Fig. 6.
Since a certain grating angle requires having a certain grating displacement correspondingly to change the cavity length, the displacement of the two soft joints should be coordinated. To generate a rotation angle of ±0.8 degrees, the soft joint A should be moved by ±30 µm, while the joint B is required to move by ±18 µm. As the soft joints always have different displacement, a rotation and a translation of the grating are generated simultaneously as required by continuous laser tuning condition.

The laser output spectra in corresponding to different grating angle are superimposed as shown in Fig. 7. With the rotation of the grating and carefully matching the grating translation, the laser output wavelength can be tuned continuous from 1503.7 nm to 1556.9 nm, corresponding to a tuning range of 53.2 nm. Meanwhile, such output is kept at a single longitudinal mode over this wide range. The laser output at further increase of the rotation angle becomes multimode since the diffraction efficiency of the deep-etched blazed grating at the selected wavelength is too small to suppress the side modes.

CONCLUSIONS

A tuning mechanical design has been demonstrated for the Littrow tunable laser to eliminate the mode hopping problem by translating and rotating the blazed grating independently. Experiment shows a tuning range of 53.2 nm based on the designed blazed grating structure. It would have numerous potential applications in optical networks.

REFERENCES