Wavelength Tuning of a Solid-State Laser with a Tilting MEMS Micromirror

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***Abstract*—Wavelength tuning of a Yb:KGW solid-state laser is presented using an electrothermally-actuated micromirror and a diffraction grating or dispersing prism. 27 nm and 7.5 nm tuning ranges are achieved using extracavity and intracavity configurations respectively.**

Keywords—MEMS, micromirror, electrothermal actuation, solid-state laser, wavelength tuning

I. Introduction

Use of optical MEMS in lasers has been an important area of optical MEMS applications in recent years. Being compact, low-power and low-cost with batch fabrication makes MEMS ideal candidates for replacing bulk optics with similar functionalities. Added functionality has been investigated in solid-state lasers through the use of adaptive optics [1] and MEMS for active laser Q-switching [2-4]. Q-switching with MEMS has also been demonstrated in fiber lasers [5] and a microchip laser [6]. Spatial and temporal control of solid-state laser outputs have therefore been demonstrated using intracavity MEMS.

This work presents spectral control of solid-state laser output properties using a MEMS micromirror combined with wavelength dispersing or diffracting optics. Although demonstrated previously in vertical cavity surface emitting lasers and DFB lasers [7], the concept of MEMS facilitated wavelength tuning is yet to be fully investigated in high-power solid-state lasers. We present the use of a tilting micromirror and a diffraction grating or dispersing prism in a Littman configuration to actively tune the output wavelength of a Yb:KGW laser. This proof-of-concept investigation highlights the extracavity and intracavity tuning capabilities and discusses the limitations of this technique.

II. Micromirror Characterization

The electrothermally actuated micromirror used in this work is shown in Figure 1. The device was fabricated using a commercially available silicon-on-insulator multi-user MEMS process offered by MEMSCAP Inc. The micromirror surface is 2 mm in diameter and is optically coated in a post-fabrication step with a 200 nm thick layer of gold, resulting in a reflectivity of 96% at λ~1 µm and a concave surface radius of curvature (ROC) of 75 mm. Four radially

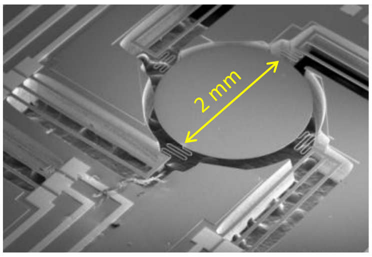

Figure 1: Scanning electron microscope image of the micromirror

positioned actuators consist each of three longitudinal beams of length 1800 µm, width 50 µm and lateral gaps of 150 µm. They are connected at one end by a 60 µm wide beam which also connects the actuator to the micromirror via a serpentine spring.

Actuation is achieved by passing a current through the two outer beams of the actuator, causing Joule heating and thermal expansion. The central beam is electrically isolated, acting as a constraint to force an out-of-plane movement of the actuator and hence tilt the micromirror. The positioning of the actuators enables 2D static control of the micromirror tilt angle. An 11 V_{dc} signal applied to an actuator results in a micromirror tilt angle of 1.2°, which is the maximum voltage applied to prevent thermal damage to the actuators. The minimum threshold for movement was measured to be 4 V_{dc}.

III. Experimental Laser Results

A. Extracavity Wavelength Tuning

A 10x5x2 mm Yb:KGW crystal was end-pumped by a fiber-coupled diode laser at λ=981 nm. Yb:KGW was used for its large gain bandwidth, enabling theoretical lasing between 1020 nm and 1060 nm. A two mirror laser cavity was aligned around the crystal, consisting of a high reflection (HR) mirror with ROC=250 mm and a flat, 80% reflective mirror as the output coupler. This setup is shown in Figure 2, together with the extracavity feedback configuration used to enable tuning of the laser output wavelength. The feedback configuration consists of a HR folding mirror with ROC=250 mm, a Thorlabs GR25-0310 diffraction grating and the micromirror. Laser output occurs from the 0^{th} order reflection of the grating. The micromirror tilt angle selects the feedback wavelength diffracted by the grating.

This work was supported in part by DSTL under grant DSTLX1000090968 and by the EPSRC under grant EP/L505080/1.

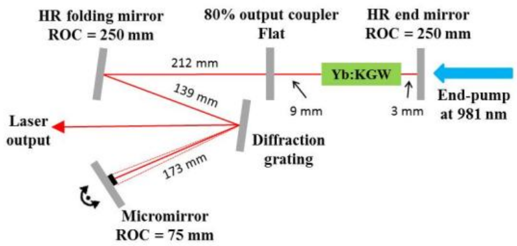

Figure 2: Extracavity laser configuration with a micromirror and a grating

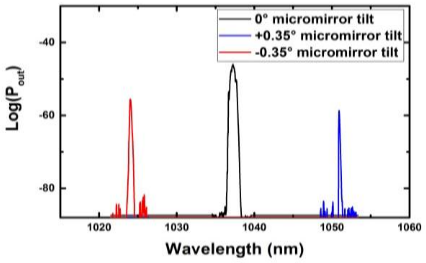

Figure 3: Plot of laser output wavelength as the micromirror is tilted for the laser in Figure 2

With no micromirror actuation the laser output had a peak wavelength of 1037 nm, a full width half maximum (FWHM) linewidth of 0.6 nm and an output power of 17 mW. By changing the micromirror tilt angle by 0.35º in either direction (7.2 V_{dc} applied to opposite actuators sequentially) the laser output wavelength could be tuned from 1024 nm to 1051 nm, as shown in Figure 3. The FWHM linewidths were 0.2 nm and 0.1 nm respectively and the laser output powers were 6 mW and 2.5 mW respectively.

B. Intracavity Wavelength Tuning

Due to the losses induced by the grating, a fully intracavity configuration was not possible. Therefore, another laser cavity was constructed using a prism to disperse the available incident wavelengths. The HR end-mirror, with ROC=250 mm, of the previous cavity was retained with the output side now consisting of an output coupler with ROC=250 mm and 98% reflectivity, a dispersing prism and the micromirror. The prism was angled close to the Brewster angle for the incident laser light. The cavity configuration is shown in Figure 4.

With no micromirror actuation the laser output had a peak wavelength of 1027 nm with a FWHM linewidth of 0.4 nm and an output power of 25 mW. For micromirror tilt angles of 0.1º in either direction, the wavelength was tunable between 1024 nm and 1031.5 nm, as shown in Figure 5, with FWHM linewidths of 0.4 nm and 0.2 nm respectively and output powers of 20 mW and 4 mW respectively.

IV. Conclusion

Wavelength tuning of a solid-state laser with a micromirror has been demonstrated with extracavity and intracavity configurations. A diffraction grating and a micromirror in an extracavity configuration

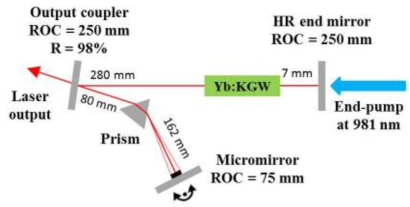

Figure 4: Intracavity laser configuration with a micromirror and a prism

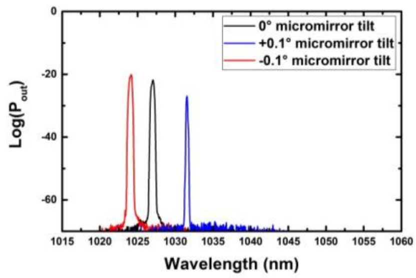

Figure 5: Plot of laser output wavelength as the micromirror is tilted for the laser in Figure 3

resulted in a wavelength tuning range of 27 nm. With a dispersing prism and a micromirror in an intracavity configuration the wavelength was tunable by 7.5 nm. Future work will be focused on optimizing the technique. A particular area of interest is improvement to the MEMS optical coating which is the current limiting factor in power-scaling the laser and the reason for the proof-of-principle demonstration being in the mW range. A low-stress dielectric coating would allow higher laser output powers suitable for defense and industrial applications.

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