Analog Tunable Gratings –
A Piezoelectric Implementation with Nanometer Deformation

Personnel

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Sponsorship

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We demonstrate a tunable MEMS grating which permits analog control over the diffraction angle, accomplished by analog deformation of the grating structure in the lateral direction. Compared to other tunable grating implementations (e.g. the Grating Light Valve and the Polychromator), our device concept trades deflection range for angular resolution. Applications for high resolution analog tunable gratings include microspectrometers, external cavity tunable lasers, and thermal compensators for wavelength multiplexer-demultiplexers.

Concepts and Design

Analog tenability of our grating device is achieved by lateral actuation forces on the grating structure, either by electrostatic comb-drives or thin-film piezoelectric actuators, as illustrated in Figure 13. With analog deformation, our devices can have resolution at 1 nm or below, three orders of magnitude better than the current digital tunable grating devices. In an electrostatic-implemented device, the grating is comprised of suspended beams supported by flexures. In the piezoelectric device reported here, the grating is deposited onto a thin 0.4 um membrane, from which the membrane is deformed to generate the desired grating period change.

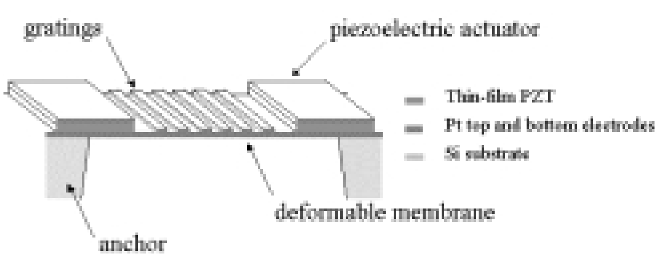

Fig. 13: Design schematic of analog tunable gratings on a deformable membrane

The driving force is provided via the deposited thin-film PZT, which contracts in the lateral direction, due to reorientation of the crystallographic domains. The membrane is correspondingly strained. The period of the diffraction grating, which is deposited onto the membrane, is thus progressively tuned and, due to the small strain range of less than 1%, is a linear response to the applied voltage. The doubly-hinged membrane design configuration, shown in Figure 1, minimizes out-of-plane displacements of the gratings from either residual stress or the actuated piezoelectric films.

For our design parameters, our analytical and finite-element models predicts a 250 nm x-axis displacement of the membrane at 10 V actuation and suggests a 3.5 nm grating period change, assuming uniform strain across the membrane. For a 632.8 nm laser on a 4 um grating period, this corresponds to an angular change of 0.14 milliradian for the first diffracted order. Given the fine control of piezoelectric actuation against voltage, this provides the resolution of a grating period change below a nanometer and angular change below a microradian. The finest achievable resolution of the total membrane displacement - of subnanometer - is limited by thermal disturbances, modal vibrations, and optical detection techniques.

Fabrication Development

The analog tunable grating process involves both surface and bulk micromachining to improve the yield of the device fabrication. The complete fabricated device is shown in Figure 14. The completed PZT has a predominant perovskite and ferroelectric characterization suggests an excellent dielectric constant of above 1200. Fatigue life cycle analysis suggests operation above 1E10 cycles under a 5 V rectangular pulse-train signal. The power consumption of the PZT film at 10 V actuation is gauged at 30 nW due to its high resistivity. The fabricated binary phase grating also has a duty cycle measured as varying between 42 to 66%, depending on the process conditions.

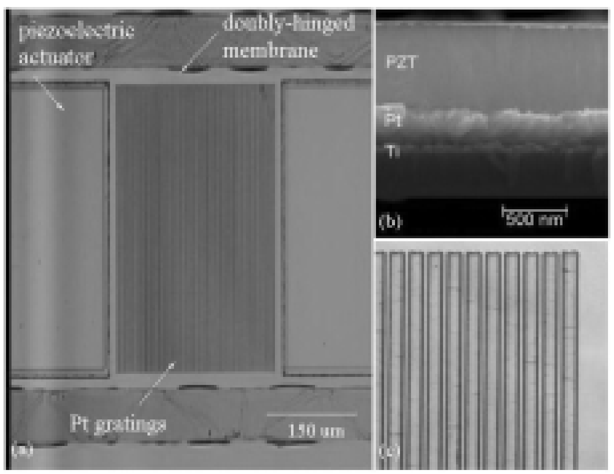

Fig. 14: (a) Piezoelectric-actuated tunable grating under 120X magnification, (b) SEM cross-section image of fabricated PZT actuator on Pt/Ti electrodes, (c) magnified view of Pt gratings with 4 um period.

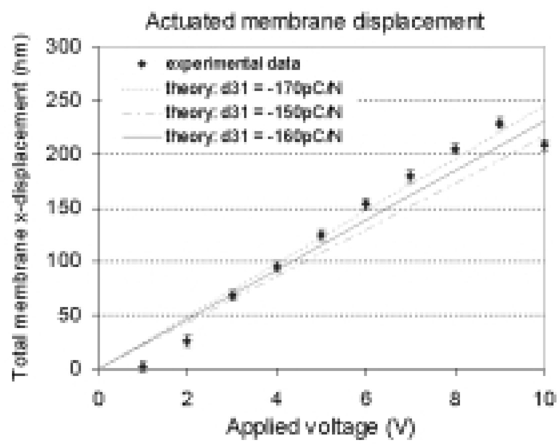

Fig. 15: Piezoelectric membrane deformation versus actuation voltage (measured with Computer Microvision system), in comparison with theory. The noise floor is 2.3 nm.

Experimental Description

The piezoelectric-actuated device demonstrated a 68 ± 2 nm membrane deformation in the in-plane x-lateral direction at 3.0 V, as shown in Figure 15. This corresponds to a 0.9 nm period change on the 4 um period grating, assuming uniformity in the membrane strain. Measurements on uniformity suggest a variation of approximately 10% across the gratings. The membrane deformation is in agreement with theory and suggests a d31 coefficient of -90 pC/N. First and second order diffraction efficiencies were measured at 7.6% and 5.0% respectively. With the as-measured deformation range, the angular change is estimated at 0.1 milliradian at 10 V applied, which suggests a resolution on the order of microradians.