MEM Analog Tunable Gratings by Electrostatic Actuation

Personnel

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Sponsorship

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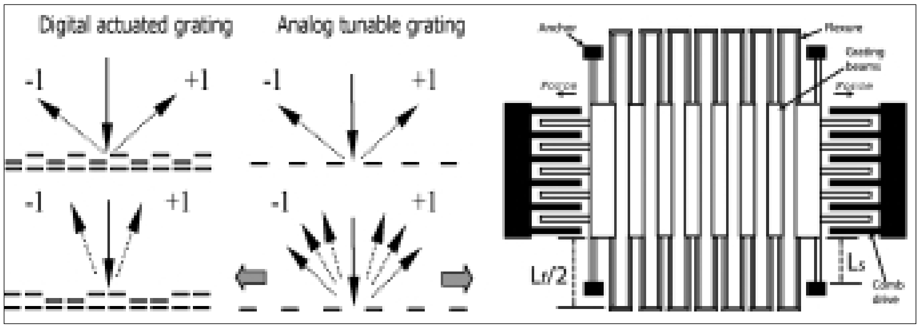
Introduction

Optical MEMS (MicroElectroMechanical Systems) is an emerging field in recent years. There are several advantages to scale bulk devices down to micron level. First, because all moving parts have much smaller inertia, MEMS are more sensitive to driving signals, and more immune to environmental disturbances such as random vibration. Second, most designs more or less share the microelectronics processing technology, which poses excellent alignment on different parts and drastically reduces the cost. We here demonstrate a MEMS tunable grating that permits analog control over the diffraction angle, accomplished by analog electrostatic actuation. Compared to other tunable grating implementations (e.g. the Grating Light Valve [1] and the Polychromator [2]), our device concept trades deflection range for angular resolution. The resolution for digital tunable gratings such as the GLV or the Polychromator is roughly the physical beam width of the grating structure. Since those beams are suspended structures, it's hard to push the resolution limit by downsizing the beams. A certain range of aspect ratio will be required for a free-standing mechanical structure. The comparison of existing digital devices and our analog design is shown in Figure 16. Instead of making a two-level structure and pulling some of the beams downward, we design a single-level structure and actuate it in the lateral direction. One of the applications will serve the *goal of this project very well: thermal compensation for wavelength multiplexer-demultiplexers.* Other applications include any kind of system in which high angular tuning mechanism is required or a compact device is pursued.



Design, simulation, and fabrication

The device principle is shown schematically in Figure 17. Two comb-drives [3] pull on both sides of a periodic structure. The structure is composed of the grating beams in the center window and the flexures which connect each beam. The flexures are essentially springs which determine the stiffness. The entire suspended structure is attached to a silicon substrate through four anchors. Several design and fabrication iterations have been done including surface micromachining, DRIE (deep reactive ion etching) micromachining, and a revised bulk micromachining with a novel lateral bump design (Figure 18). Since the structure is very compliant, we met serious stiction problem in both the vertical and the horizontal directions. In the last iteration, a single-mask process was used. Starting with an SOI (silicon on insulator) wafer, we used photolithography followed by DRIE to pattern the grating structure and the comb-drives in the device silicon layer. The buried oxide sacrificial layer was removed by an HF etching step. Then a maskless metallization step was adopted to coat the reflective surface and bonding pads. The fabricated device under optical microscope is shown in Figure 19.

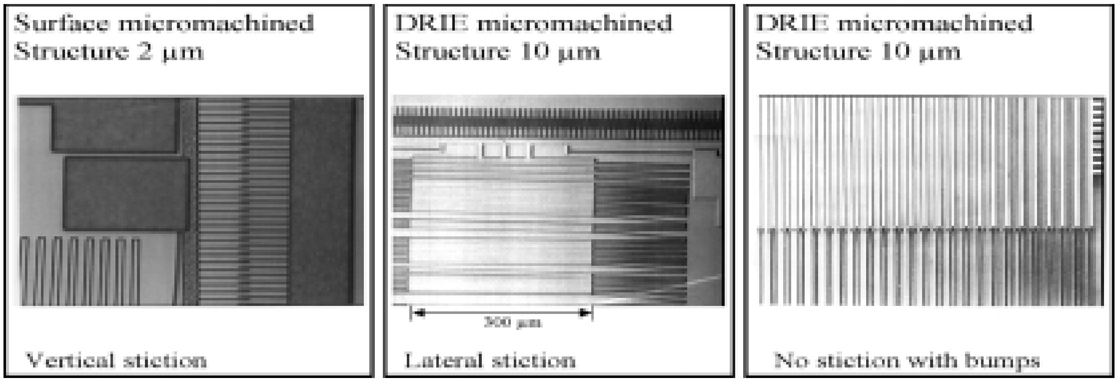


Fig. 18: Three iterations of fabrication

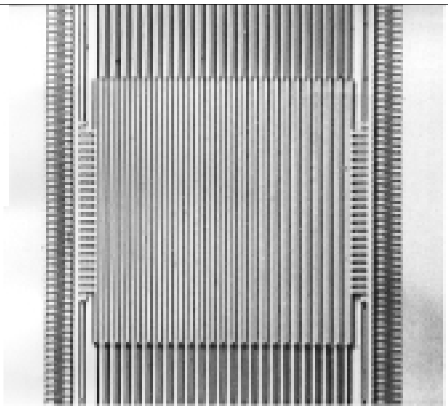


Fig. 19: Device under microscope (130X).

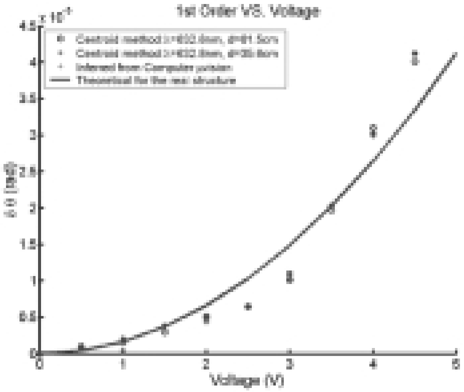


Fig. 20: Diffraction angular change against applied voltages.

Testing results

Device testing was conducted with two different methods: optical beam steering measurement and the Computer Microvision technique [4]. The former was done by imaging the first diffracted order on a CCD camera and comparing the centroid locations before and after actuation. The latter technique involves obtaining three-dimensional images of microscopic targets using the optical sectioning property of a light microscope and post-processing the combined images to analyze the images with nanometer precision. Results from different testing setups are plotted in Figure 20 which shows that three different measurements match the theory very well. The tuning range is 50 mrad at 5 volts and the resolution is roughly an order of magnitude smaller.

Conclusion

We have designed, fabricated, and tested an electrostatic analog tunable grating. The experimentally measured tuning range of our first-generation devices was 50 mrad with actuation voltage less than 5V, and the open-loop angular resolution was approximately 5 mrad. By redesigning the stiffness of the device and implementing feedback control, we expect a wide tunable range of milliradians with mrad resolution at actuation voltage below 30 Volts.