THE POLYCHROMATOR: A PROGRAMMABLE MEMS DIFFRACTION GRATING FOR SYNTHETIC SPECTRA

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ABSTRACT

We report here the design, fabrication and demonstration of an electrostatically actuated MEMS diffractive optical device, the Polychromator grating. The Polychromator grating enables a new type of correlation spectrometer for remote detection of a wide range of chemical species, offering electronic programmability, high specificity and sensitivity, fast response and ruggedness. Significant results include: (1) The first demonstrations of user-defined synthetic spectra in the 3 – 5 µm wavelength regime based upon controlled deflection of individual grating elements in the Polychromator grating; (2) The first demonstration of gas detection by correlation spectroscopy using synthetic spectra generated by the Polychromator grating.

INTRODUCTION

MEMS technology enables many innovative optical devices. The Polychromator grating is an array of a large number of long, narrow optically reflective elements whose vertical positions are electrically controlled. If the element length is many optical wavelengths, the width a few optical wavelengths, and vertical positions controllable to a fraction of a wavelength, the Polychromator can function as a programmable diffractive optical device. Specifically, as described below, the Polychromator grating elements can be positioned to generate a desired multi-line, or polychromatic, spectrum at a given diffraction angle. Furthermore, this synthetic spectrum can be designed to match the infrared absorption spectrum of a molecule and used in a correlation spectrometer for the spectroscopic detection of that species.

MEMS DEVICE DESIGN

The Polychromator gratings reported here are designed to generate synthetic spectra in the 3-5 µm wavelength range. A grating consists of 1024 individually addressable diffractive elements each 10 µm wide by 1 cm in length. The vertical position of a grating element is to be controlled over approximately a 2 µm range with an accuracy of about 0.1 µm. Because of the difficulty of providing individual inputs to 1024 lines, the first devices fabricated used only 132 pads for signal and ground, compatible with a readily

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DEVICE FABRICATION

The Polychromator grating device is fabricated by polysilicon surface micromachining. Two polysilicon layers are used for the actuated structure, and two for electrical

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GRATING ACTUATION RESULTS

The individual diffractive elements of the Polychromator grating are actuated electrostatically. Beam deflection depends on the applied voltage, electrode length, distance between support posts, beam thickness, residual stress, and free-space gap. Combinations of mask design and process parameters are selected to result in structures which maximize travel while maintaining moderate actuation voltage. The vertical position of each element is

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OPTICAL OPERATION AND SYNTHETIC SPECTRA

When infrared radiation strikes a grating, the phase shift of the wavefront on reflection from a given diffractive element depends upon vertical position of that element. The diffracted radiation is the sum of the wavefronts diffracted from the individual grating elements. Since the vertical position of the elements of the Polychromator grating can be controlled by the voltages applied, it is possible to program

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CORRELATION SPECTROSCOPY AND GAS DETECTION

A correlation spectrometer correlates the spectrum from a sample with a reference spectrum, providing sensitivity and specificity, fast response, and mechanical and optical simplicity. The need for a reference cell containing a

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CONCLUSIONS

We have demonstrated the Polychromator, a programmable MEMS diffraction grating capable of generating synthetic spectra. The innovative electromechanical design of the electrostatically controlled grating elements uses leveraged bending to allow controllable actuation over the nearly the full gap. Fabrication utilizes multilevel polysilicon surface micromachining. A design algorithm is used to calculate the displacements of the grating elements that will create a desired diffraction spectrum, along with the voltages required to create these displacements. Synthetic spectra have been generated as designed in the 3 – 5 µm wavelength regime. Two such designed spectra have been used to detect CO_2 in the first demonstration of correlation spectroscopy using synthetic reference spectra generated by a programmable MEMS device.

The Polychromator concept will lead to an instrument for stand-off detection of many chemical species. Advantages include electronic programmability, specificity to the desired species and immunity to interference, and fast response, in a miniature, rugged, low-power instrument.

Future efforts will include improvements to grating element yield to improve diffraction efficiency, and development of Polychromator gratings and control electronics offering individual control of 1024 grating elements for improved spectral resolution.

REFERENCES

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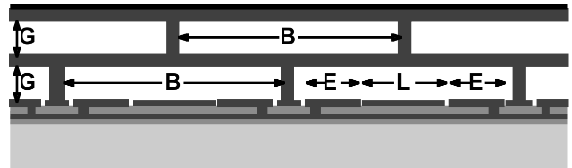

Figure 1. *View of Polychromator grating beam structure in cross-section for unactuated state (B is the doubly-supported beam length, E is the length of one actuating electrode, L is the ground pad length, and G is the lower and upper free-space gap).*

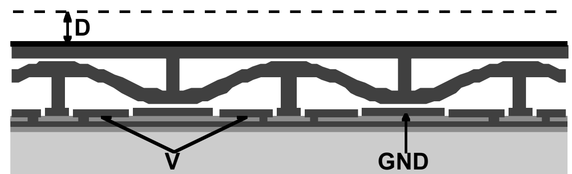

Figure 2. *View of beam structure in cross-section for actuated state The lower beam undergoes bending, while the top mirror beam remains flat and deflects vertically (D is the vertical displacement from the original position).*

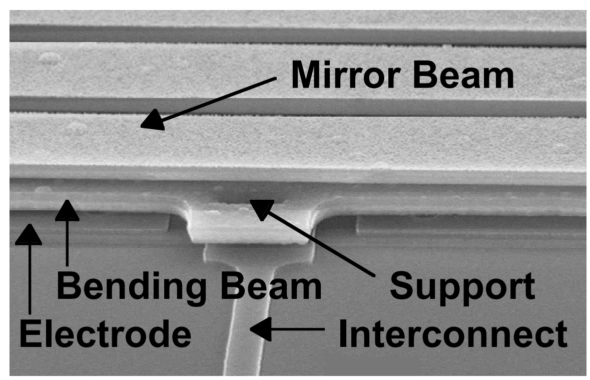

Figure 3. *SEM of MEMS grating showing the double beam design, support structure, interconnects, and electrodes.*

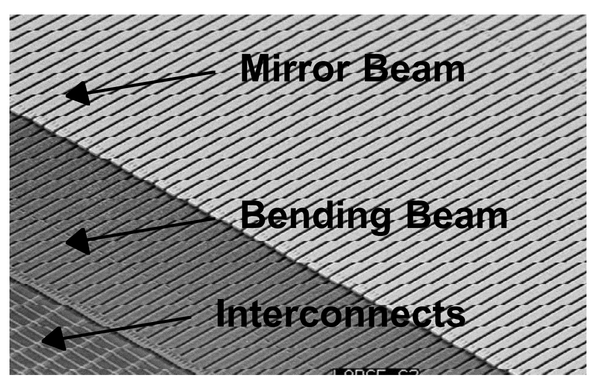

Figure 4. *SEM of the edge of a MEMS Polychromator grating showing interconnects, lower bending beam, and upper mirror beam. Beam widths are 10µ, and they extend 1 cm in length.*