WC2 (Contributed Oral)
2:30 PM – 2:45 PM

Fast Optical Phased Array with Ultra-Lightweight High-Contrast-Grating Mirrors

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ABSTRACT

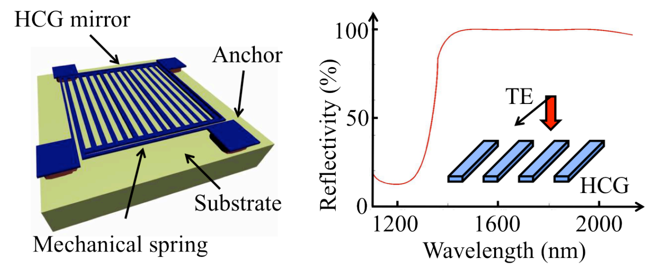
We report an optical phased array (OPA) using high-contrast-grating (HCG) as an electrostatically actuated mirror for the purpose of free space fast beamsteering. In this paper, several attractive properties of HCG mirror are introduced such as single material, high reflectance along a wide bandwidth and low-mass inertia and the fabrication result is shown. $\pm 10^{\circ} \times 10^{\circ}$ with 2° beam width is observed at 1550 nm wavelength using HCG optical phased array.

1 INTRODUCTION

OPA with fast beamforming (MHz frequencies) are of interest for 3D imaging, targeting, sensing, and 3D display applications. Previously, OPAs with liquid crystal and micro-electro-mechanical system (MEMS) phase shifters have been reported. However, the liquid crystal OPAs are limited to millisecond response time [1]. The performance of MEMS OPAs are limited by the micromirrors. Traditional MEMS micromirrors are either too heavy (e.g., bulk Si mirror or distributed Bragg reflectors) or suffer from temperature- or power-induced curvature change (e.g., micron-thick Si mirror with metal coating) [2]. In this paper, we report on a novel MEMS-based fast OPA with ultra-lightweight mirrors made of HCG. The HCG mirror consists of a single layer of 320 nm-thick silicon with sub-wavelength grating (pitch = 1380 nm). It exhibits both high reflectivity (>99.9 % at 1550 nm) and broad reflection band (1400 to 2000 nm). Fast optical phase shifter with such HCG mirror exhibits a resonance frequency of 340 kHz and actuation voltage of 20V. Two-dimensional beamforming ($\pm 10° \times 10°$) has been demonstrated with an 8×8 array.

2 DESIGN AND FABRICATION

The schematic of the MEMS OPA with HCG mirrors is shown in Figure 1(a). The HCG mirror is tethered by four symmetric flexure springs, and actuated electrostatically by applying a voltage between the mirror and the common substrate. Incident light excites multiple (typically two) optical modes in the grating bars. By properly designing the grating pitch, width and thickness, the transmitted light can be completely suppressed by destructive interference among the modes, leading to high reflectivity [3]. Figure 1(b) shows the calculated reflection spectra of the HCG mirror used in this experiment using rigorous coupled wave analysis. High reflectivity is obtained for TE-polarized light (polarization parallel to grating) over a broad wavelength band (1400-2000 nm), with a peak reflectivity of >99.9 % at 1550 nm wavelength where the beam is steered.



(a) (b)

Figure 1. Reflectivity spectra of the HCG mirror in the normal-incident TE-polarized field.

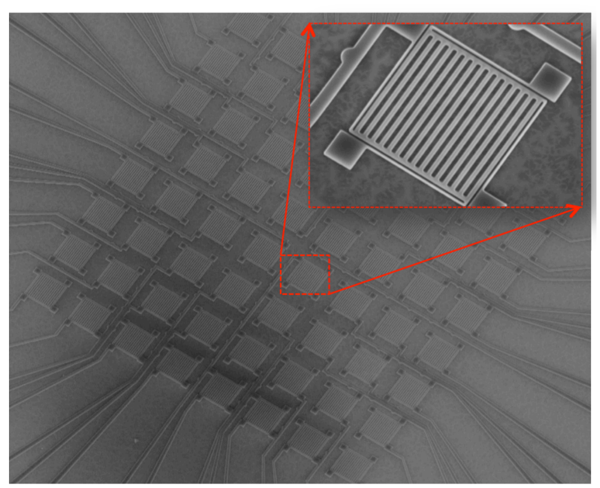


Figure 2. SEM image of the HCG array. The inset image indicates the HCG mirror composed of HCG, mechanical springs and anchors.

Figure 2 shows the SEM image of an 8×8 OPA. The inset shows the close up view of an HCG pixel (20×20 μm^2 area on 35 μm pitch). The designed grating has the following parameters: period = 1380 nm, width = 590 nm and thickness = 320 nm. All the HCG pixels are electrically connected by doped silicon fan-outs on buried oxide layer from their anchors to wirebonding pads outside. This device was fabricated on silicon-on-insulator (SOI) wafers with one photolithography step performed using ASML300 deep ultraviolet (DUV) stepper. After etching, the HCG structures are released by hydrofluoric acid vapor.

3 MEASUREMENT

Figure 3 shows the displacement of the structure versus the applied voltage, where the voltage varies from 0 V to 20 V using the developed stroboscopic interferometer system. The maximum phase shift is measured to be 1.7π at 20 V and then the HCG pixel clamps down across 2 μm actuation gap of the used SOI wafer.

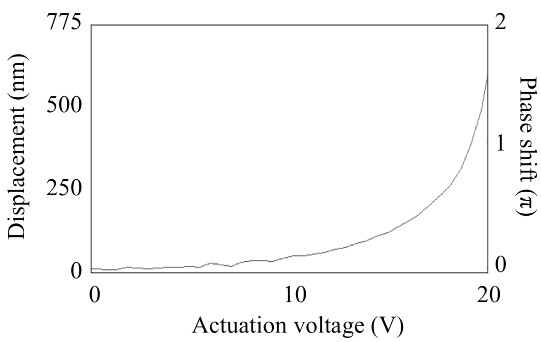


Figure 3. Measured displacement of the HCG mirror versus applied voltage.

Figure 4 shows the far-field patterns of the steered optical beams amplified by a pair of lenses in 4-f configuration. The unbiased OPA shows a strong zero-th order beam and grating sidelobes at 20° in both x and y directions (Figure 4(a)). Maximum steering in the horizontal direction (10°) is achieved by applying π phase shifts to every other column (Figure 4(b)), and maximum steering in the vertical direction (10°) is achieved by applying π phase shifts to every other row (Figure 4(c)). The measured beam profiles are shown in Figure 4(d) and Figure 4(e). The instantaneous beam width is 2°. The experiments agree very well with the theoretical prediction.

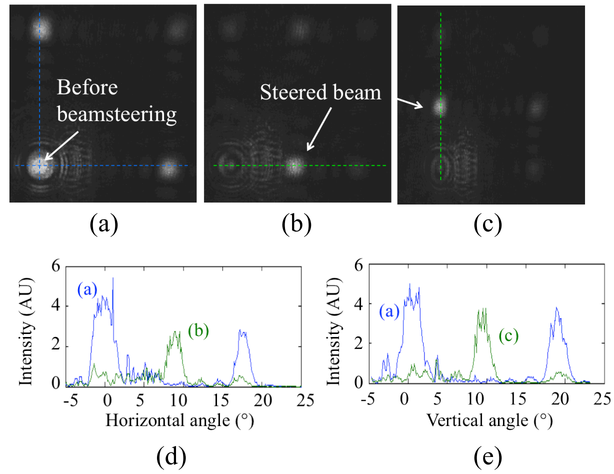


Figure 4. Images of the two dimensional steered beams (a) no phase shift, (b) with π phase shift of every other column of the HCG array, and (c) with π phase shift of every other row of the HCG array. (d) Beam intensity vs. angle along the dotted lines in (a) and (b). (e) Beam intensity vs. angle along the dotted lines in (a) and (c).

4 CONCLUSIONS

In summary, we have demonstrated a fast optical phased array using an 8×8 array of electrostatically actuated HCG mirrors. The 20×20 μm^2 HCG mirror has a mass of only 139 pg, much lighter than traditional MEMS mirrors. The HCG phase shifter has a resonance frequency of 340 kHz by laser Doppler vibrometer and an actuation voltage of 20 V. The 8×8 OPA has a total field of view of ±10°×10° and a beam width of 2°.

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