Grating light valves: a SiGe based approach towards monolithic integration of MOEMS

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The Grating Light Valve (GLV) is a microelectromechanical reflection grating producing bright and dark pixels in a display system by controlled diffraction of incident light due to electrostatic deflection of microbeams. Nowadays, monolithic integration of MEMS on CMOS is getting more popular because CMOS-integrated MEMS exhibit less parasitic and have reduced assembly and packaging cost over hybrid approaches. Relatively low deposition temperature (~450°C) of poly-SiGe compared to poly-Si (deposition temp. ~800°C) makes it suitable for back end processing. In this work we report the functioning of PECVD prepared poly-SiGe GLVs in terms of their response to amplitude and frequency of the applied actuation voltage.

Introduction

Grating Light Valve[1,2] (GLV) display pixels are reflection type diffraction gratings consisting of fixed-fixed type microbeams. In the non-actuated state, coplanar beams specularly reflect light in the 0^{th} order (OFF state), whereas after actuation the alternate movable beams deflect downwards turning the pixels ON. At a deflection of $\lambda/4$, maximum amount of light is diffracted to the $\pm 1^{st}$ order. Display systems consisting of this technology provide huge improvement in contrast ratio, high resolution and brightness[1, 2]. This sort of fixed-fixed beam systems can be described by a spring capacitor model. The electrostatic force associated with the constant voltage drive mode is nonlinear and shows the well known phenomenon of pull-in[3, 4].

Another important issue is the integration of MEMS with CMOS[5]. Compared to hybrid integration, post processing of MEMS monolithically on top of CMOS can lead to increased functionality, performance, reliability and a reduced size and cost in volume applications. However the high deposition temperature (~800°C) of poly-Si deteriorates all the metal interconnects in the underlying CMOS. On the contrary, poly-SiGe structural layers are deposited at low temperature (~450°C), which retains the performance and reliability of the CMOS electronics[6], while still guaranteeing the desired material properties.

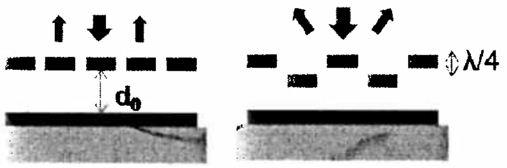

Fig.1. Functioning of a grating light valve.

So, the main aim of our work is to use the poly-SiGe module to fabricate GLVs. In this work we report the functionality of GLVs with two different beam lengths; a clear length dependent shift in resonance frequency of the devices is shown. We demonstrated that even for beams with no residual tensile stress high switching speed can be obtained and a reasonable voltage dependent change in diffraction efficiency can be produced.

Fabrication and appearance of GLVs

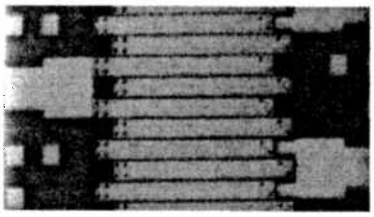

Fig. 2. Microscope view of GLV pixel consisting of two fixed and two movable beams.

The SiGe structural layer used in these devices is 300 nm thick with around 30nm of Al coating on top of it. The CVD deposited structural SiGe layer was grown at a chuck temperature of 460°C with a SiH_4: GeH_4 flow ratio of 0.9:1 and a varying B_2H_6 flow over thickness to tune the stress gradient. After roughness reduction of the structural layer by CMP, further 5nm of SiC barrier layer and 30nm of sputter deposited AlCu were added to increase the reflectivity. Finally the samples were released in vapor HF. Fig. 2 shows the pixel configuration of the GLVs. A total of 16 pixels constitute a single GLV device, two different beam lengths of 50 µm and 200 µm were fabricated with a pitch of 4.8 µm and 93% fill factor.

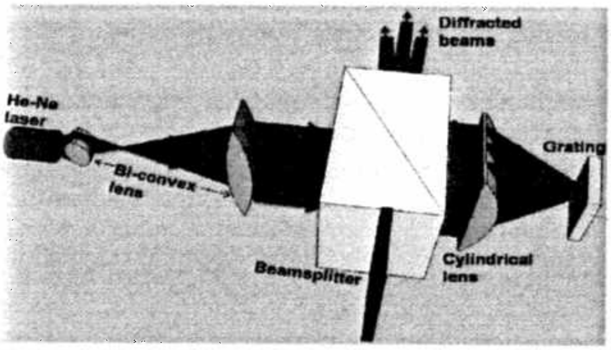

Fig. 3. GLV characterization set-up.

Experimental set-up

Fig. 3 shows the experimental set-up used for characterization of the GLVs. The two convex lenses in the front acts as a collimator where as the cylindrical lens focuses the light as a horizontal line with uniform intensity at the center of the microbeams. The beamsplitter helps in separating the incoming and outgoing light. A photodiode in series with an electrical spectrum analyzer gives the intensity of the diffracted light as a function of amplitude and frequency of the applied actuation voltage.

Results and Discussion

COMSOL Multiphysics[7] using a fixed-fixed beam model was used to find the pull-in voltage of the devices to ensure a safe operation. As can be seen from Fig.4b the pull-in voltage for 50 µm and 200 µm beams varies widely, which can be verified easily using an analytic spring capacitor model as reported in literature[3, 8]. An experimentally found

Young's modulus of 143 GPa and a density of 4725 Kg/m^3 were used for the simulation and the theoretical calculations[10].

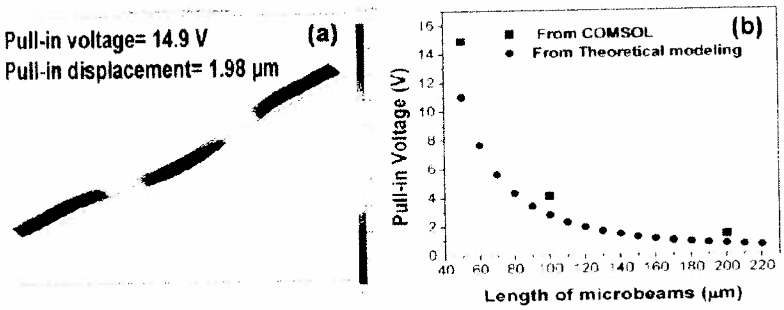

Fig. 4. (a) COMSOL simulation of bending of a 50 µm long and 4.5 µm wide fixed-fixed SiGe beam due to electrostatic attraction with an airgap of 0.6 µm, (b) variation in pull-in voltage due to change in beam length as found from COMSOL and analytical model.

The GLV devices were thoroughly characterized after determining the safe operation region. We determined the resonance frequency to estimate the switching speed of the devices and measured the change in optical intensity under DC actuation. To find the frequency response of the devices a small sinusoidal signal (V_{AC}) was used in combination with a larger DC voltage (V_{DC}) to modulate the beams around a stable deflected distance. This creates a force with two different harmonics of the applied signal but the 1st harmonic dominates largely over the 2nd one because of the small amplitude of the sinusoidal signal ($F \propto [(V^2_{DC} + \frac{V^2_{AC}}{2}) + 2V_{DC}V_{AC}\cos\omega t + \frac{V^2_{AC}}{2}\cos 2\omega t]$).

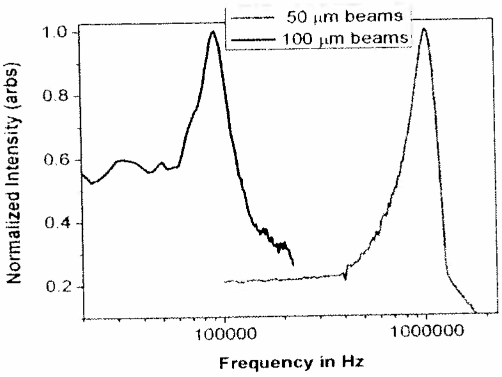

Fig. 5. Small signal frequency response of GLVs with 50 and 200 µm long beams.

The small signal frequency response of the devices is shown in Fig. 5 where a clear shift in resonance frequency with decreasing length can be observed. Using a spring capacitor model theoretical[9] resonance frequencies of 703 KHz and 44 KHz were found respectively for the 50 and 200 µm beams which is in relative agreement with the experimentally determined values of 1.02 MHz and 92.5 KHz. The deviation between experimental and theoretical values may be related to an uncertainty in the experimentally determined Young's Modulus and the density of poly-SiGe material. Also for the theoretical calculations we did not take into account the stress generated inside the beams because of initial bending caused by the applied DC voltage.

The response of the GLVs to a DC voltage is shown in Fig. 6. Whereas for the 200 µm beams the change is less prominent and the dark state intensity is high, a significant improvement for the 50 µm beams can be observed. The change in 0^{th} order diffraction intensity for the 50 µm beams is shown in fig. 6c. It can be observed that the total reduction in 0^{th} order intensity is approximately 150 nW, this power gets divided equally in the two diffraction orders increasing intensity of both $\pm 1^{st}$ orders by around 70 nW as seen from fig. 6 b. The main reason for initial intensity in the 1^{st} order (without any actuation voltage) is the absence of any residual stress in the beams, which may cause the longer beams to buckle and hence create a grating structure even before actuation. This can be improved by introducing tensile stress in the beams.

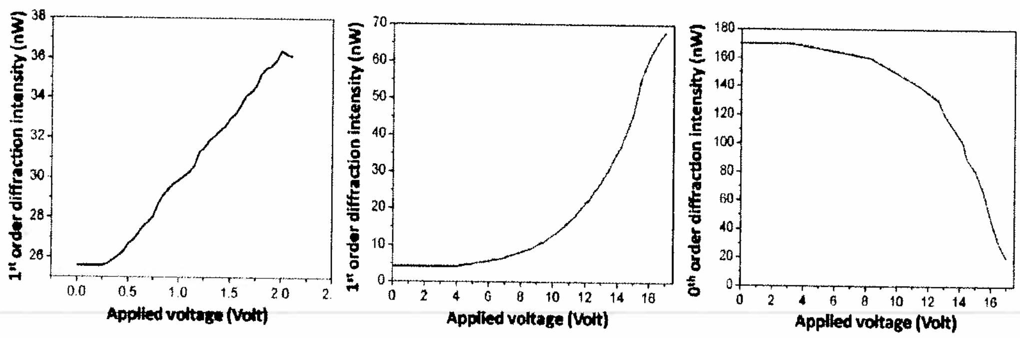

Fig. 6. Change in 1^{st} order diffraction intensity with actuation voltage for two different GLVs with (a) 200 µm, (b) 50 µm beam length, whereas the change in diffraction intensity in the 0^{th} order is shown in fig (c) for the 50 µm GLVs.

Conclusion

We have demonstrated the operation of a poly-SiGe based GLVs. Shorter GLVs of 50 µm showed an overall excellent behavior with a resonance frequency of 1.02 MHz. Next we will try to implement residual stress in the microbeams which will improve the switching speed and the dark state intensity level.

Acknowledgements

We thank IWT SBO GEMINI project for financial assistance.

References

[1] D. Bloom, "The Grating Light Valve: Revolutionizing Display Technology," SPIE Proceedings, 3013, 165-171, Projection Displays III Symposium, 1997

[2] Trisnadi *et al*, Photonics West 2004, Micromachining and Microfabrication symposium, Paper 5348-05

[3] G.M. Rebeiz, RF MEMS: Theory, Design and Technology, John Wiley & Sons, p. 21-31, 2003.

[4] D. Peroulis *et al*, IEEE Trans. On Microwave theory and techniques, vol. 51, 259-270, 2003.

[5] R. Jablonski, M. Turkowski and R. Szewczyk, Recent Advances in Mechatronics, Springer Berlin Heidelberg, 521-525, 2007.

[6] A. Witvrouw, Scripta Materialia, vol. 59, 945-949, 2008.

[7] M. Uncuer, et al, Proc. COMSOL conference, p. 439, 2007

[8] S. Chowdhury *et al*, J. Micromechanical Systems, vol. 15, 639-651, 2006.

[9] K. Wang *et al*, J. Microelectromechanical Systems, vol. 9, 347-360, 2000.