Static and dynamic characterization of poly-SiGe Grating Light Valves

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We present the fabrication and the characterization results of poly-SiGe grating light valves showing excellent contrast. We also discuss the different dimensional parameters that affect the switching time of the device through squeeze film damping.

Keywords- Poly-SiGe, grating light valve, squeeze film damping

I. INTRODUCTION

Grating Light Valve[1, 2] (GLV) display pixels are diffraction gratings, consisting of electrostatically movable fixed-fixed microbeams. Non-actuated coplanar beams behave like a mirror giving specular reflection. After actuation, the alternate movable beams are deflected downwards and the grating starts diffracting, which turns the pixel ON. GLV based displays[3] can provide a huge improvement in contrast, resolution and switching speed over other types of MEMS based displays.

At the same time poly-SiGe based MEMS are gaining increasing interest because they can be post-processed above CMOS[4, 5]. Poly-SiGe layers have a lower deposition temperature (~450°C) compared to Poly-Si (~800°C) but still possess the necessary mechanical properties and reliability required for MEMS.

Hence in this work we use poly-SiGe layers for developing GLVs and characterized their overall optical and mechanical performance. We were able to produce sufficient tensile stress within the poly-SiGe microbeams resulting in excellent flat structures, which is one of the primary requirements for a GLV to work efficiently and reach high contrast. Due to the small airgap between the microbeams and the underlying substrate and due to fast operating speed of the GLVs, squeezed film damping[6] becomes the dominant mechanism affecting its dynamic response. We show the variation in the amount of damping with different dimensions of the microbeams and the resulting effect on the switching time of the individual pixels.

II. DEVICE FABRICATION

The CVD deposited structural SiGe layer was grown on top of a Ti/TiN adhesion layer with a SiH_4: GeH_4 ratio of 0.9:1 and a B_2H_6 (1% in H_2) flow ratio of 90 sccm at a wafer temperature of ~450° C. Following roughness reduction of the SiGe layer by Chemical Mechanical Polishing (CMP), extra layers consisting of 5 nm SiC and 30 nm Al were added. Finally the samples were released with a 5 step release recipe in a vapor of HF and ethanol with a ratio of 4:5. Beams with lengths of 50 μm, 75 μm, 100 μm and 150 μm were fabricated each with periods of 3.0 μm, 4.2 μm and 5 μm. A fixed gap of 0.3 μm among the consecutive microbeams was maintained. We used

two different sacrificial layer thicknesses of 400 nm and 800 nm for our devices. Figure 1 shows a SEM picture of a fabricated GLV device.
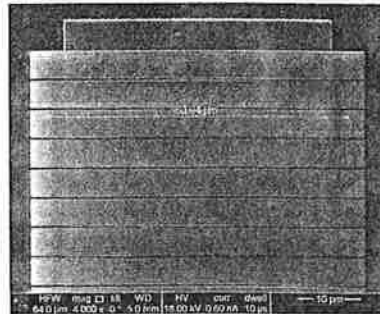

Fig. 1. Scanning Electron Microscope view of a GLV device consisting of alternately moving and fixed microbeams with length of 50μm.
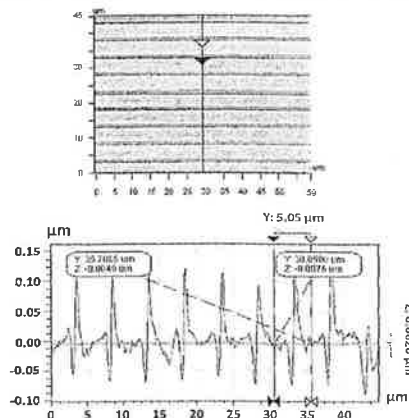

Fig. 2. Optical profile of a 100 um long non-actuated GLV device as measured with WYKO.

III. STATIC MEASUREMENTS

One of the stringent requirements for a GLV to function well is to achieve sufficient flatness of the microstructures. Any height difference among consecutive microbeams will result in scattering and increases the noise in the dark state. The profile of a 100 μm long grating device in non-actuated condition as obtained with a WYKO optical profilometer is shown in Fig. 2. A height difference as low as 2.6 nm among consecutive microbeams was obtained. Figure 3 shows the

diffraction efficiency as function of the applied voltage for devices with different length and for a wavelength of 633 nm (He-Ne laser). As a result of the excellent flatness control of the devices, a contrast of ~1250:1 could be obtained consistently for these devices with a maximum efficiency of 67% for the ±1st order of diffracted light, in line with simulations for these devices.
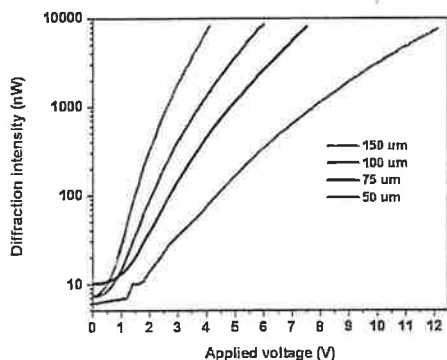

Fig. 3. Analog response of GLV devices showing an excellent optical response.

IV. EFFECT OF SQUEEZE FILM DAMPING

As the GLV beams can be approximated by a mass-spring-damper model working below the cut-off frequency[7] associated with the squeeze film theory, viscous drag due to the surrounding fluid becomes the dominant damping mechanism in these structures. The viscous damping coefficient for parallel plate movement is given by:

$$c_v \propto \mu l w^3 / h_0^3 \qquad (1)$$

Hence the damping ratio of the system is defined as:

$$b = c_v / 2 m \omega_r \qquad (2)$$

where, μ is the viscous coefficient of the surrounding fluid, h_0 is the height of the airgap, w is the width, l is the length, m is the mass and ω_r is the natural vibration frequency of the beams.
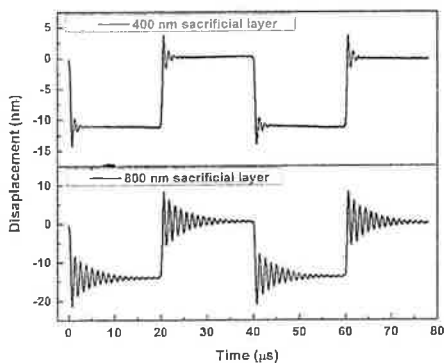

Fig. 4. Variation in settling time with change in airgap for a 50 μm long and 4.7 μm wide microbeam.

If the damping is too low then the resonance effects result into ringing of the microbeams when a step voltage is applied. If the damping is too large then also the switching time is degraded. We used laser doppler vibrometry to characterize the response of the GLVs to a square wave pulse train.

Fig. 4 and 5 show the variation in settling time (equilibrium ± 2%) with the change in dimensional parameters. We decreased the airgap and increased the width of the microbeams to maximize the damping in the system. A maximum resonance frequency of 1 MHz was obtained for the 50 μm long microbeams. With variation in the dimensions, a minimum settling time of 2.2 μs was achieved for these microbeams corresponding to a width of 4.7 μm and an airgap of 400 nm.
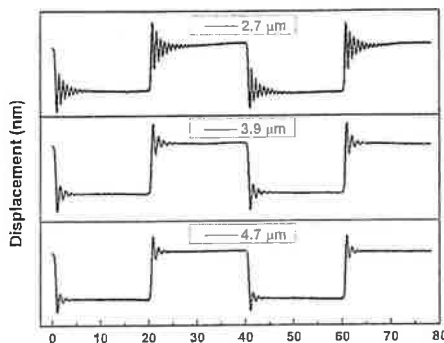

Fig. 5. Variation in settling time with change in width for a 50 μm long microbeam.

V. DISCUSSIONS

We demonstrated a fully operational poly-SiGe based GLV device. A maximum contrast of 1250:1 was obtained for our GLVs. We varied the airgap and the width of the microbeams to increase the damping and hence reduced the settling time of the devices to a minimum value of 2.2 μs.

VI. ACKNOWLEDGMENT

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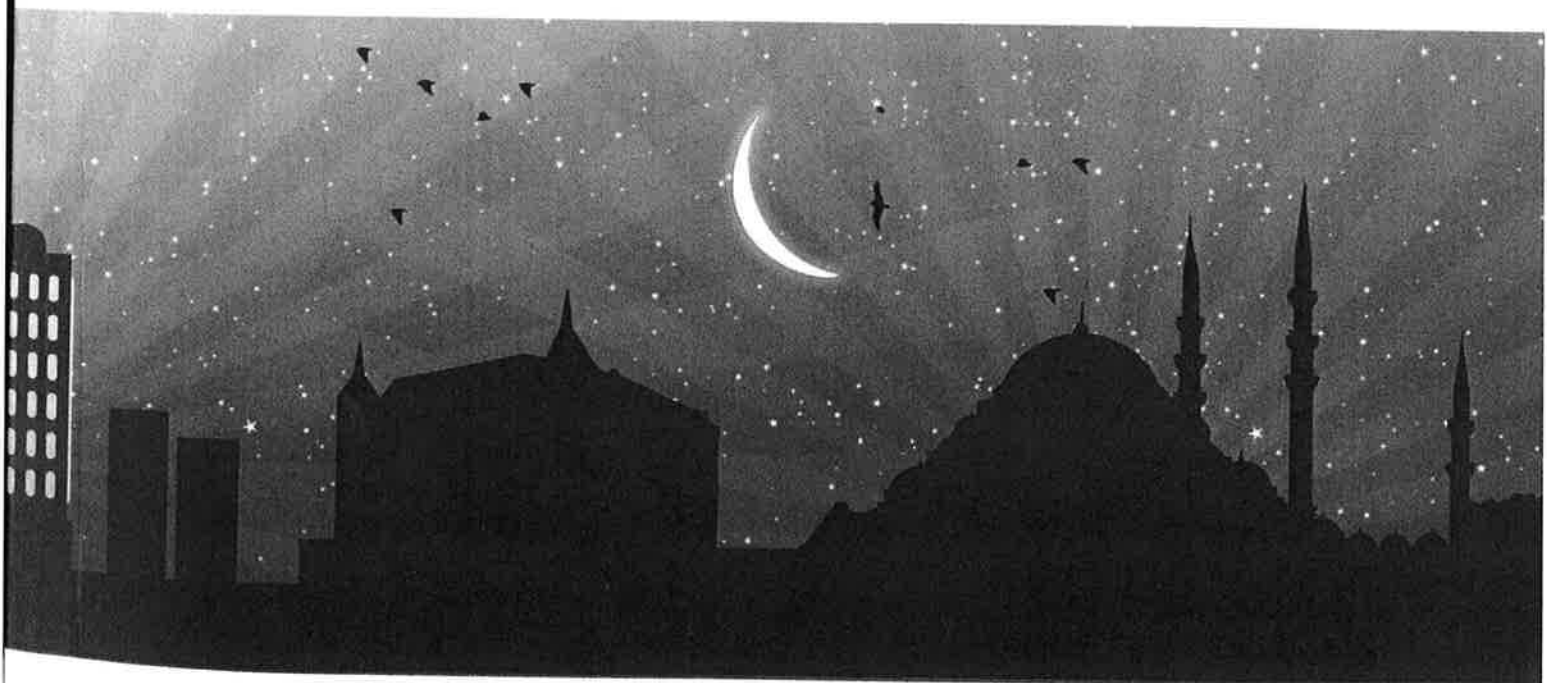
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