Optical Modulation with Nanohole Gratings Made by Nanoimprint Lithography
J. L. Skinner1,2, A. A. Talin3,4, and D. A. Horsley1,2
1University of California, Davis, CA; 2Berkeley Sensor & Actuator Center; 3Center for Integrated Nanotechnologies; 4Sandia National Laboratories, Livermore, CA 94551, Tel: (925) 294-2398, Fax: (925) 294-1377, Email: jlskinn@sandia.gov

Abstract – A silver film perforated with an array of circular nanoholes fabricated by thermal nanoimprint lithography is brought in and out of contact with a quartz superstrate to yield a 60 % amplitude modulation in reflectivity.

I. INTRODUCTION
Modern nanolithography techniques allow the realization of 1D and 2D gratings with subwavelength features and engineered reflection and transmission properties. The fact that gratings can be fabricated in a single thin-film layer makes them attractive for use in microelectromechanical systems (MEMS) devices; recently both MEMS tunable lasers [1] and optical modulators [2] based on actuated subwavelength gratings have been realized. In metallic gratings, the excitation of surface plasmons [3] has been observed to result in effects such as extraordinary optical transmission at narrowband resonant wavelengths [4]. The refractive index of the dielectric medium surrounding the grating influences the wavelength of these resonances. We have previously demonstrated sensitive refractive index measurement of fluids in contact with a grating by measuring the wavelength shift of a reflectance resonance [5]. Here, we demonstrate the modulation of reflected light by changing the gap distance between a resonant grating and a solid dielectric.

We used thermal nanoimprint lithography (NIL) to fabricate the metallic gratings. NIL has proven to be a viable lithography method for nanometer scale features [6] and is better suited to cost-efficient fabrication when compared to traditional serial methods, such as electron-beam or focused-ion beam lithography. Our fabrication process combines NIL with MEMS fabrication techniques to realize nanohole arrays on electrostatically-actuated MEMS pixels, allowing monolithic integration of multicolor optical modulators. Reflectivity measurements indicate a modulation amplitude of 60 %. Rigorous coupled-wave (RCW) analysis is used to accurately model the reflectivity of the grating.

II. EXPERIMENT AND SIMULATION
Nanohole gratings are fabricated as shown in Fig. 1. Polymethylmethacrylate (PMMA) is spun to a thickness of 350 nm and baked at 150 °C for 2 min. A Si master is then pressed into the PMMA at 200 °C and 400 psi for 5 min. After cooling to 60 °C, the template is separated from the wafer leaving a patterned layer of PMMA on the aluminum layer. An O2 plasma is used to remove the residual PMMA in the holes before dry etching the silicon. Silver is then evaporated onto the Si grating at a 45 degree angle while rotating at 20 RPM. A completed silver grating is shown in Fig. 2.

An Ocean Optics USB2000 optical spectrometer coupled to a microscope was used to measure the reflectivity from the grating. Broadband light from a tungsten filament lamp is directed through the microscope onto the silver grating at normal incidence. Zero-order reflected light is collected by the microscope objective and measured with the spectrometer. Reflectivity with the grating in contact with the quartz superstrate and out of contact with the superstrate is shown in Fig. 3. A modulation amplitude of 60 % was achieved.

A commercial program (GD-Calc) was used to model the reflectivity of the grating. This program performs RCW analysis, solving Maxwell’s equations through a Fourier series approximation of the electromagnetic field. The modeled reflectivity spectrum, shown in Fig. 4, closely matches the experimental spectrum. The modeling results employed a Fourier series with five orders. Higher order approximations should improve accuracy with the expense of increased computation.

III. CONCLUSIONS
We have fabricated resonant nanohole arrays by starting with a silicon substrate and using nanoimprint lithography and shadow evaporation. These arrays show a pronounced reflectivity minimum that has been experimentally measured with an OSA and accurately simulated with RCW analysis. When the grating is brought in and out of contact with a quartz superstrate, the reflectivity shows a 60 % amplitude modulation. Modulation of reflected light using this approach is readily achieved at the chip level by combining NIL with conventional micromechanical fabrication techniques.
REFERENCES


