Phonon Polariton Reflectance Spectra In a Silicon Carbide Membrane Hole Array

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Abstract

We report on the experimental observation of the effect of periodic hole arrays in the infrared reflection spectra of suspended polycrystalline silicon carbide (poly-SiC) membranes. The poly-SiC was deposited by low pressure chemical vapor deposition (LPCVD), patterned with contact photolithography, and etched by reactive ion etching (RIE). The spectra are shown to be strongly dependent on the pitch and aperture size of the hole arrays, indicating poly-SiC has promise as a mid-IR optical material.

Keywords: Optical MEMS, Nanophotonics, Plasmonics, Phonon Polaritons, Silicon Carbide

1 INTRODUCTION

Advances in micro- and nano-fabrication techniques have stimulated research in photonic structures and, in particular, the use of surface polariton materials for optical devices [1]. Most of this work has focused on metallic subwavelength gratings and aimed at producing surface plasmon polaritons in the visible and near-IR regimes.

Recently, single crystal SiC gratings have been made with focused ion beam patterning [2]. This paper reports the mid-IR reflection from subwavelength hole arrays patterned in LPCVD poly-SiC using conventional optical lithography and reactive-ion etching. We have previously reported on the transmission spectra from these poly-SiC films [3]. Film deposition via LPCVD of poly-SiC from 1,3-disilabutane and dichlorosilane precursors can yield conformal films with controlled residual stress, making it an attractive structural layer for MEMS [4].

2 DESIGN & FABRICATION

Hole arrays of various permutations of pitch spacing (*a*) and hole diameter (*d*) were included into a single contact lithography mask to explore the dependency of reflection spectra on array and hole geometry. In general the hole arrays were designed for the mid-IR regime ($a \approx \lambda \approx 10\mu m$).

Starting with a double-side polished (100) Si wafer, 1.5µm of undoped poly-SiC was deposited at 800°C. The "back-side" SiC was removed by plasma RIE etching with a mixture of Cl_2 and HBr gases [5] in a LAM TCP 9400 etcher. Next, a hard mask of low temperature oxide (LTO) was deposited by CVD at 400°C. The LTO was patterned using contact photolithography using 1.6µm photoresist and magnetically enhanced reactive ion etched in an Applied Materials P5000 etcher using CF_3 and Ar. After stripping the photoresist the array pattern was transferred from the hard mask into the SiC film with another Cl_2/HBr RIE. The gratings were released from the Si substrate by a gas phase XeF_2 etch in a Xactix e1 Xetch tool. The release etch is extended long enough that the released hole arrays are >20µm from the handle wafer surface. The XeF2 etching leaves a rough silicon surface under the suspended hole array, so that Fabry-Perot reflection between the hole array and the substrate is insignificant. Finally, the remaining hard mask LTO and backside LTO were removed by a dip in 6:1 BOE. Figure 1 shows the fabrication process in schematic cross-section. Figure 2 shows SEMs of the completed hole arrays. The holes have a double slope profile with an overall slope of ~80°.

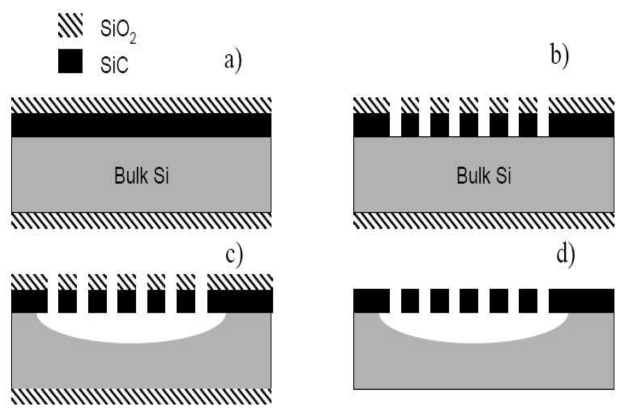

Figure 1. Schematic of fabrication process flow.

3 OPTICAL ANALYSIS

The fabricated hole arrays were spectrographically analyzed using a Nicolet 6700 FT-IR system connected to a Nicolet Continuum Infrared Microscope. Figure 3 shows the reflection spectrum for a hole array with *a*=10µm and thickness (*t*) of 1.5µm for different hole diameters (*d*). Figure 4 shows the reflection spectrum for a hole array with *a*=8µm and thickness (*t*) of 1.5µm for different hole diameters (*d*). In both cases the spectra are measured relative to the reflectance of a polished Au mirror.

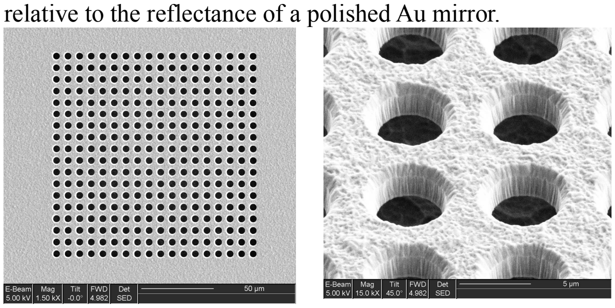

Figure 2. (left) SEM of a full 150µm x 150µm array with *a*=8µm and *d*=4.8µm. (right) Higher magnification SEM of the same grating at a 45° angle.

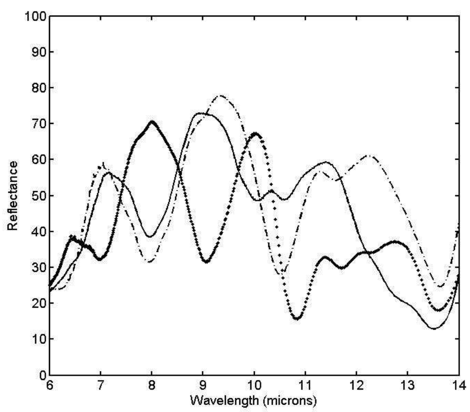

Figure 3. Experimental reflectance spectra from a 1.5µm thick poly-SiC film with *a*=10µm and *d*=4.8µm (dash-dotted), *a*=10µm and *d*=5.6µm (dotted), and *a*=10µm and *d*=6.5µm (solid).

In both the 10µm and 8µm pitch arrays, the effect on hole size (and thus fill factor) has a strong effect on the reflection spectra. This is particularly true in the polariton gap (λ = 10.4-12.6µm) in which SiC is known to have a relatively flat reflectance approaching unity. Looking at the 10µm array (Figure 3) the ~10.5µm reflectance dip expected due to surface plasmon polaritons is seen regardless of aperture size, although the central wavelength and minimum intensity of this dip are affected by aperture size. For the 8µm hole array, the effects of varying the aperture size are also extremely pronounced. A large reflectance peak at 12µm is suppressed as the aperture size grows, and eventually displays a split into two separate resonances.

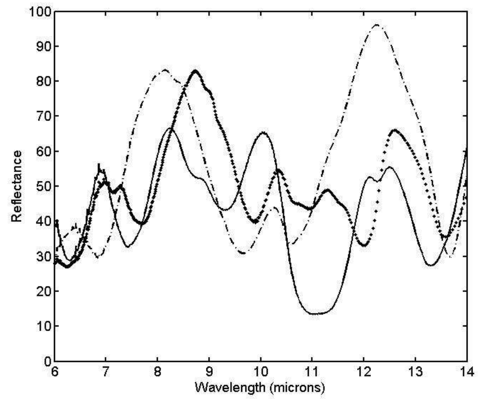

Figure 4. Experimental reflectance spectra from a 1.5µm thick poly-SiC film with *a*=8µm and *d*=2.5µm (dash-dotted), *a*=10µm and *d*=3.9µm (dotted), and *a*=10µm and *d*=5.6µm (solid).

4 CONCLUSION

The reflection spectrum of LPCVD poly-SiC films patterned with a regular array of subwavelength circular holes has been shown to display strong dependence on the periodicity and fill factor of the subwavelength hole array. Because of the displayed grating dependent control of the spectra, poly-SiC shows considerable promise as a mid-IR optical material. Efforts for FDTD simulations for reflection spectra of our hole arrays are currently ongoing.

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