Fabrication of Bio-Inspired Photonic Structures for Antireflectivity in Cadmium Telluride for Infrared Detectors

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Abstract:
Moth-eye structures are emerging as an anti-reflection surface capable of enhancing broadband transmission and functioning at off-normal incidence, providing an alternative to interference based thin-film coatings. A procedure has been developed by the Gordon group to produce moth-eye structures on cadmium telluride (CdTe) for infrared detection applications. Photoresist was spun onto a CdTe wafer, which was then coated with colloidal silica nanoparticles to form a mask. A CF4/O2 inductively coupled plasma etch was used to reduce the size of the nanoparticles, after which the photoresist was etched by O2. This allows for a CH4/H2/Ar etch of the CdTe, followed by an additional O2 clean and an acetone rinse to strip the mask. The result was a set of CdTe columns retaining the order of the colloidal mask. This has been shown to increase transmission through the interface between the air and CdTe by 10% over a range of wavelengths from 3 to 8 µm.

Introduction:
There is a constant need for improvement in infrared detectors for military, medical, or astronomic applications. Mercury-cadmium-telluride devices with interference based thin-film coatings form the current state of the art for infrared sensing devices in the range of 1-25 µm. These antireflective coatings function only for normal incidence, and require deposition of many materials to perform across a broad wavelength range. Moth eyes have a structure of nanoscale protrusions, causing a gradient index of refraction that decreases reflection. Biomimetic moth-eye structures provide antireflective properties superior to those of interference based thin films on silicon and germanium, functioning over broad wavelength ranges and at off-normal incidence, and can be fabricated using a one mask, one etch process [1]. By adapting this process to CdTe, a superior antireflective coating (Figure 1) for infrared detectors can be fabricated. Additionally, this geometric pattern decreases the area of the surface, which will reduce dark current. The combination of higher transmission and lower dark current will allow for more sensitive devices. This work adjusted the process for etching a moth-eye pattern into silicon by the addition of both a protective photoresist layer and an additional etch to reduce the mask size. This resulted in successful pattern transfer into CdTe and improvement in transmission in the near infrared.

Experimental Procedure:
The two-step process used in silicon was found to be ineffective for CdTe, as the etch angle was too shallow. A mask reduction step was added to allow plasma to reach the surface, then a protective photoresist layer was needed to prevent surface damage to the CdTe during the mask transfer.

Figure 1: (a) SEM of a moth’s eye [2]. (b) SEM of fabricated moth-eye nanostructure on CdTe.

Figure 2: Moth-eye structure process flow and etch parameters.
reduction (Figure 2). The initial attempt without a mask reduction technique consisted of Langmuir-Blodgett deposition of 310, 540, and 960 nm colloidal silica nanospheres onto the 8 µm CdTe layer grown epitaxially on <211> silicon by collaborators at the U.S. Army Research Laboratory. Next, a reactive ion etch (CH$_4$/H$_2$/Ar) was performed with clean steps (O$_2$). The mask was stripped with an inductively coupled plasma silica etch (CHF$_3$/O$_2$). The resulting structure did not result in distinct pillars (Figure 3a), so a mask reduction step was introduced.

First attempts at mask reduction involved adding a silica etch (CHF$_3$/O$_2$) before the CdTe etch. Crystal growth was observed, and energy-dispersive x-ray spectroscopy indicated fluorine on the sample's surface, suggesting a CdF$_2$ precipitate. The presence of this growth led to micromasking (Figure 3b). A layer of protective photoresist was spun before the deposition of the silica mask. The previous silica etch had too high an etch rate in photoresist, so additional etches were developed. First, a SF$_6$/Ar etch was used (Figure 3c), then CF$_4$/Ar was found to have higher selectivity to silica over photoresist. A vertical oxygen etch was performed after the mask reduction step to expose the CdTe (Figure 3d), and an isotropic oxygen etch was used to strip the photoresist, lifting off the silica mask (Figure 3e). The optical properties of the sample were analyzed using a custom Fourier-transform infrared spectrometer with integrating sphere.

**Results and Conclusions:**

A 10% increase in transmission was observed though the sample in the near IR, bringing the absolute transmission to the theoretical maximum of ~ 70% for wavelengths below 4 µm (Figure 4). This increase did not continue into the mid IR, likely due to shallow etch depths. At no wavelength of interest did transmission fall below the initial sample.

The final procedure developed consisted of spinning photoresist on the wafer, depositing the colloidal silica mask, reducing the size of the silica nanospheres, etching through the photoresist, etching the CdTe, and stripping the photoresist. This process successfully etched a moth-eye structure into CdTe. Nanosphere size controls pillar spacing, and mask reduction controls pillar width. The mask pattern was reliably transferred onto the surface, and the expected increase in transmission was observed in the near infrared.

**Future Work:**

Mask and etch procedures will be adjusted for better control over pillar geometry, with a focus on controlling the shape of the pillar edges and increasing the aspect ratio. Theory suggests this will increase transmission in the mid IR. Additionally, this process will be applied to HgCdTe devices so that changes in dark current can be measured.

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**References:**
