Femtosecond Laser-Assisted Microstructuring of Silicon for Novel Detector, Sensing and Display Technologies

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Arrays of sharp, conical microstructures are obtained by stucturing the surface of a silicon wafer using femtosecond laser-assisted chemical etching. The one step, maskless structuring process drastically changes the optical, material and electronic properties of the original silicon wafer. These properties make microstructured silicon viable for use in a wide range of commercial devices including solar cells, infrared photodetectors, chemical and biological sensors, and field emission devices.

Previously, we reported the formation of sharp, micrometer-sized conical structures in quasi-ordered arrays after irradiating a silicon surface with hundreds of femtosecond-laser pulses in the presence of sulfur containing gases [1,2]. Figure 1 shows a scanning electron micrograph of the microstructured silicon surface at an angle of 45°. The laser irradiation also creates a nanometer scale, highly disordered sulfur-doped surface layer. The combinration of sulfur-doped surface layer and conical microstructures results in near-unity absorption of light from 250 nm to 2500 nm [2,3].

We recently found that the laser-affected surface layer forms a photodiode junction with the undisturbed substrate wafer beneath. Figure 2 shows the *I-V* characteristics of this junction in a dark environment. The high absorption of light from 250 nm to 2500 nm and the photodiode junction allow us to fabricate silicon-based photodetectors for both the visible and the near infrared [4]. The spectral responsivity (wavelength dependence of photocurrent per unit incident power) for such a device is shown in Figure 3. At a small bias of –0.1 V, the responsivity in the visible is nearly ten times greater than that of commercially available silicon PIN photodiodes. At wavelengths with energies below the band gap of ordinary silicon (1200-1650 nm) the reponsivities are five orders of magnitude higher than responsivities measured in Si avalanche photodiodes before amplification. We are also working toward creating efficient photovoltaic devices that take advantage of the extended wavelength absorption region. Nearly a third of sunlight is at energies below the band gap of silicon and is therefore not converted into usable energy by conventional silicon solar cells. We hope to use the simple microstructuring process to make silicon-based solar cells that convert more of the sun’s spectrum into electric energy.

In addition to its striking optical properties, microstructured silicon displays remarkable field emission characteristics. The rapidly growing field of field emission devices requires unique emitting materials that are robust, easily fabricated, and that have favorable emission characteristics. Figure 3 shows an *I-V* measurement for a 2 x 2 mm^2 area of microstructured silicon. The low turn-on fields and high current yields make the textured silicon ideal for use in field emission displays, ion thruster propulsion, and microwave amplification.

In this talk we will present the unique optical and electronic properties of microstructured silicon, discuss the formation process of the conical microstructures, and review the chemical and structural make-up of the surface that are responsible for the novel optoelectronic properties. We will also discuss future directions for this technique including structuring of new materials, incorporation of new ambient gases, and better control over the position and density of the microstructures themselves (Figure 4).

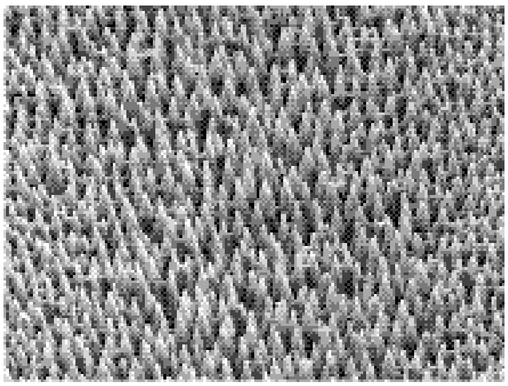

Figure 1: A scanning electron micrograph of silicon microstructures taken at a 45° angle and 3000x magnification.

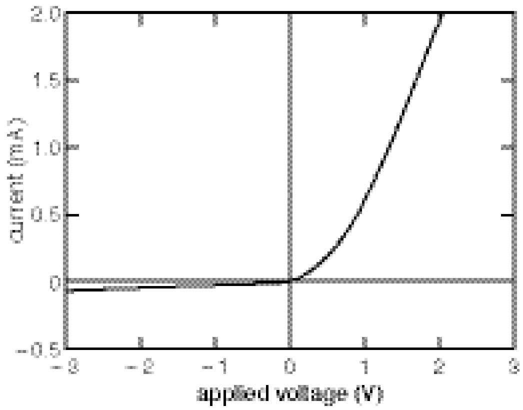

Figure 2: Current-voltage characteristics of microstructured silicon photodiode without illumination.

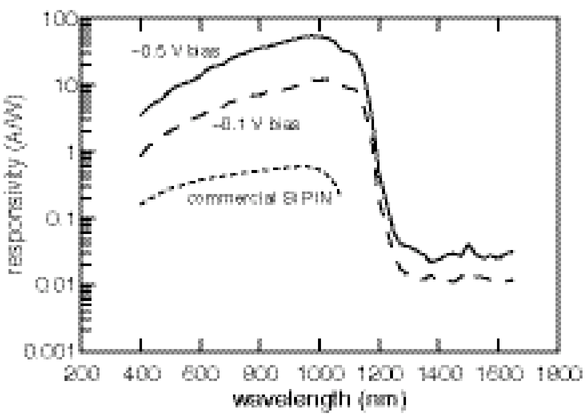

Figure 3: Spectral responsivity (wavelength dependence of photocurrent per unit incident power) of microstructured silicon device at two bias values. The responsivity of a commercial silicon PIN photodiode is shown for comparison.

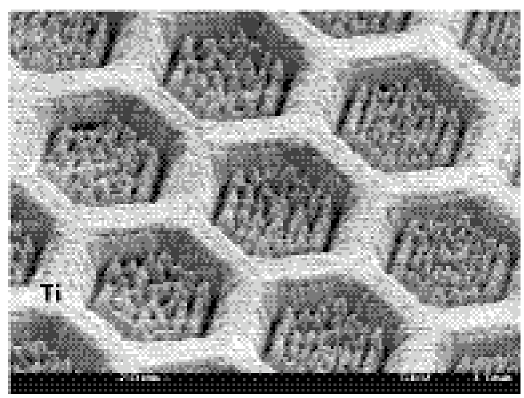

Figure 4: A scanning electron micrograph of structures made on Titanium using a spatial mask to control their organization.

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