High-efficiency photovoltaic devices using pulsed laser microtextured silicon surfaces provide an alternative method for efficient light trapping.

For solar energy technology to be competitive as an alternative energy source, further improvements in photovoltaic (PV) efficiency and reduced manufacturing costs are needed. Bulk silicon continues to dominate the solar energy market. In order to achieve higher solar cell efficiency, techniques minimize bulk silicon surface reflection losses. However, alternative methods are also needed to reduce surface reflection loss from monocrystalline, polycrystalline, and thin-film silicon surfaces as well as other PV materials.

Currently, chemical anisotropic etching of monocrystalline silicon and isotropic chemical etching of polycrystalline silicon are used for surface microtexturing in order to efficiently trap incident solar radiation and improve solar cell efficiency. Antireflection coatings in combination with chemical microtexturing have provided reflection losses up to 5–10%. Lasers are also playing an important role in silicon solar cell manufacturing, and new laser-based processes are being investigated. We have achieved pulsed laser microtexturing of silicon surfaces for PV device applications with reflection losses of less than 5%.

We used a high-power, ultrashort pulsed laser to form self-organized microtextures on a silicon surface over broad spectral and angular range.\(^1,2\) The incident laser light was absorbed by silicon, causing an increase in temperature, which led to melting and vaporization. By using short pulsed lasers under narrow laser processing conditions, we caused self-organized microtextures to form. The microtextured surfaces appeared black to the naked eye and enhanced the silicon light absorption, offering minimal reflection over a broad wavelength and angular range.

Figure 1 shows a scanning electron microscope (SEM) image of a pulsed laser microtextured surface after brief chemical etching. We performed this step to remove any laser-induced surface damage. The texture height is about 2–3 microns, producing desired reflection losses of less than 5%. We investigated the optical properties of the laser microtextured surface. Figure 2 shows the sum of the reflection, scattering, and transmission values. The data show high light absorption by silicon after laser microtexturing over a broad incidence angle and at different wavelengths. This indicates that laser-microtextured silicon could be used for efficient photovoltaic devices due to the extremely low reflection losses.\(^3,4\)

We fabricated these devices on laser microtextured and chemically etched samples using a simple silicon solar-cell fabrication process.\(^3,5\) The resulting PV devices were characterized for their current-voltage features and for quantum efficiency. Figure 3 shows the current voltage measurement data for the AM1.5 sun illumination condition (solar power density of 100 mW/cm\(^2\)). We obtained a photovoltaic efficiency of 15.3%. A current density of 35.4 mA/cm\(^2\) was achieved with an open circuit
voltage of 0.58V. We believe this was one of the first studies to fabricate photovoltaic devices on laser microtextured silicon surfaces.

In our photovoltaic devices, the back surface was not passivated, so it is possible to improve the device efficiency. The interface defects due to silicon dangling bonds cause higher charge recombination losses. To better understand the efficiency losses, we made internal quantum efficiency measurements (see Figure 4). These data show that there is a decrease in quantum efficiency in the short and long wavelength spectral regions. Further improvements in front and back surface passivation should lead to higher solar cell efficiency.

By depositing a charged dielectric film (passivation process) of materials like amorphous silicon, silicon nitride, or thermally grown silicon dioxide, we could achieve a decrease in charge recombination losses. We expect that a back surface passivation with point contacts using a lithography process could yield an enhancement of about 1.5% to 2% in device efficiency.

Either way, surface passivation will play an important role because of the large surface area generated during the microtexture process. We estimate that further improvements in surface passivation should lead to another 1% to 1.5% improvement in the photovoltaic device efficiency. Optimization of short-circuit current could lead to additional improvement. By combining all of these techniques, a device efficiency of 19% to 20% may be achievable.

In summary, we demonstrated high-efficiency silicon PV devices using pulsed laser microtextured silicon surfaces for efficient light trapping. In our future work, we expect to make further improvements in PV devices by optimizing the fabrication process, in particular through better front and back surface passivation.

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Continued on next page
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