

## Formation of inverted-pyramid structure by modifying laser processing parameters and acid etching time

Je-Wei Lin<sup>c,\*</sup>, En-Ting Liu<sup>a</sup>, Chien-Hung Wu<sup>b</sup>, Ing-Jar Hsieh<sup>a</sup>, and Tien-Sheng Chao<sup>c</sup>

<sup>a</sup> Department of Electrical Engineering, Chung Hua University, 30012, Taiwan

<sup>b</sup> Department of Electronics Engineering, Chung Hua University, 30012, Taiwan

<sup>c</sup> Department of Electrophysics, National Chiao Tung University, 30012, Taiwan

This paper is to investigate the possibility to fabricate the inverted-pyramid structure on silicon wafer base solar cell by using laser scribing technology. The UV spectrometer and SEM had also been used to observe the reflectance and microstructure of the wafer surface. In this experiment, a Q-switched Nd:YAG laser operating at wavelength of 1064nm is used to scribe on the p-type wafer surface to produce inverted-pyramid structure. In order to remove the laser damage, we used acid etching and Alkaline etching solutions to smooth the damage region and inverted pyramid structure formed, simultaneously.

### Introduction

In order to control optical path (1), investigation on the front surface of the solar cell is necessary. Most of the solutions are to use acid-etching to form pyramid structure (2-3) on the surface. For this, it shows the lower reflectance at wavelength from 300nm to 1000nm. However, the acid-etching parameters, like ratio of acid solution, acid-etching time, acid-etching temperature and etc., are sensitive to fabricate a pyramid structure. Any one of the above parameters will strongly affect the pyramid structural geometry and light incident path. The density of short-circuit current ( $J_{sc}$ ) in solar cell will decrease acutely.

Surface texturing on silicon based solar cells are becoming the standard-process in terrestrial applications. Erenow, many techniques of surface texturing have been developed. One of the groups have focused on the use of dry etching process, either in conjunction with a mask process to achieve a regular pattern features, or without a mask process to produce a period random texture. One of the groups have focused on the use of wet etching process to produce an easily and low-cost pyramid texture. Above of the all technologies, the inverted pyramid geometry is considered to be the best cell texturing design for light trapping.

In this work, we attempt to investigate more stability, lower reflectance and easy processing inverted-pyramid structure by using laser technology. For the laser parameters, we control different laser power density, laser power frequency, laser power focus and laser power velocity in this experiment. According to the above parameters, we can design the width, depth and spacing of the texture. The width and depth of the texture could be fabricated by modifying laser power density, laser power frequency and laser focus. The depth-to-width aspect ratio is the key condition for the texture. The spacing of the each texture is also a non-ignorable factor. If the depth-to-width aspect ratio is too low, the optical loss will be critical. The same result occurs when having wide spacing of

the texture. If the spacing of the texture is too wide, the light will be reflected back to atmosphere at this flat region. After laser scribing, the laser induced surface damage removed is necessarily. We used acid etching and Alkaline etching solutions to smooth the damage region and inverted pyramid structure formed, simultaneously.

### Device Fabrication

P-type boron doped monocrystalline silicon wafer were used as a substrate. Wafers had the following parameters: thickness  $\sim 200 \mu\text{m}$ , resistivity 1-3  $\Omega\text{cm}$  and area  $7.14 \text{ cm}^2$ . First, saw damage removed by NaOH solution at temperature  $80^\circ\text{C}$ . Then the contamination removed by HPM solution at temperature  $80^\circ\text{C}$  and DHF. The nitride film was deposited by plasma-enhanced chemical vapor deposition for a masking layer. The texture in the form of honeycomb has been produced by means of Q-switched Nd:YAG laser of 1064 nm in wavelength. Parameters of laser treatment were as follows: maximum output power 20 W, pulse repetition frequency 4-20 kHz, diameter of the laser spot size  $\sim 20\text{-}30 \mu\text{m}$  and laser beam speed 600-900 mm/s. The optimum laser parameters were determined experimentally by creating textures with different laser settings. After laser surface texturization, the laser induced surface damage removed by KOH solution at temperature  $80^\circ\text{C}$  and inverted-pyramid-like structure formed, simultaneously. The masking layer was removed by B.O.E. Then the contamination removed by HPM solution at temperature  $80^\circ\text{C}$  and DHF. The emitter of sheet resistance  $75 \Omega/\square$  was formed at temperature  $830^\circ\text{C}$  using liquid  $\text{POCl}_3$  as the doping source. Phosphorous-silicate glass (PSG) was removed by DHF. The ARC layer of nitride ( $\text{Si}_3\text{N}_4$ ) was deposited by means of plasma-enhanced chemical vapor deposition. The front and back contacts were formed by screen-printing technology. Front contact was printed with silver paste. Back contact was printed with aluminum paste. Then co-firing was performed in an infrared belt furnace at peak temperature  $775^\circ\text{C}$  and belt speed 200 cm/min. The IV parameters have been measured at room temperature under  $100 \text{ mW/cm}^2$  AM 1.5G. The micro-structures of surface texturing were investigated by scanning electron microscope (SEM) and the reflectance was measured by UV spectrometer.

### Results and Discussions

After laser scribing, we used different kinds of etching solution to remove laser induced damage and fabricate the inverted-pyramid structure. From figure 1. shows SEM micrograph cross-section of the wafer (a) with laser texturization (b) flat electrode contact region. From figure 2. shows SEM micrograph Top view of the wafer with laser texturization. (a) The inverted-pyramid-like structure were fabricated by laser power : 17(watt). (b) Electrode and inverted-pyramid-like structure. From figure 3. shows SEM micrograph cross-section of the wafer with ARC layer. From figure 4. shows (a) Reflectance of the different laser power scribing (b) Reflectance of laser scribing at 17(watt), and removal of laser induced damage layer at different acid etching time. From figure 5. shows reflectance of laser scribing at 19(watt), (a) with different NaOH solution etching time. (b) with different KOH solution etching time. (c) with different acid solution etching time. From figure 6. shows (a) IV characters of laser scribing at 17(watt), (b)QE of the Cell were passivated w/ or w/o  $\text{HNO}_3$ -Oxide.

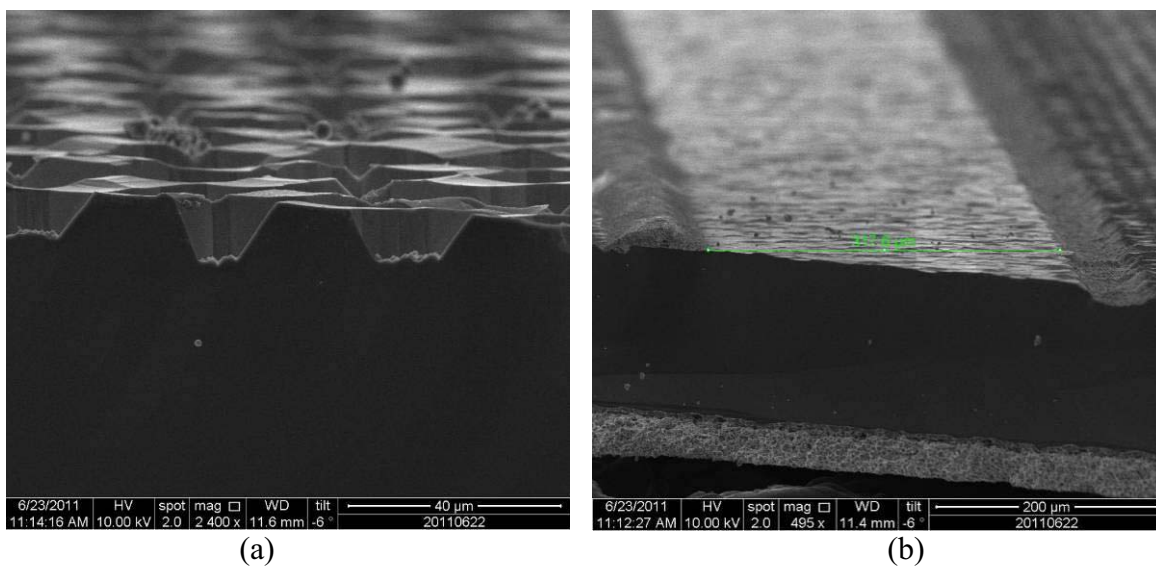


Figure 1. SEM micrograph cross-section of the wafer (a) with laser texturization (b) flat electrode contact region.

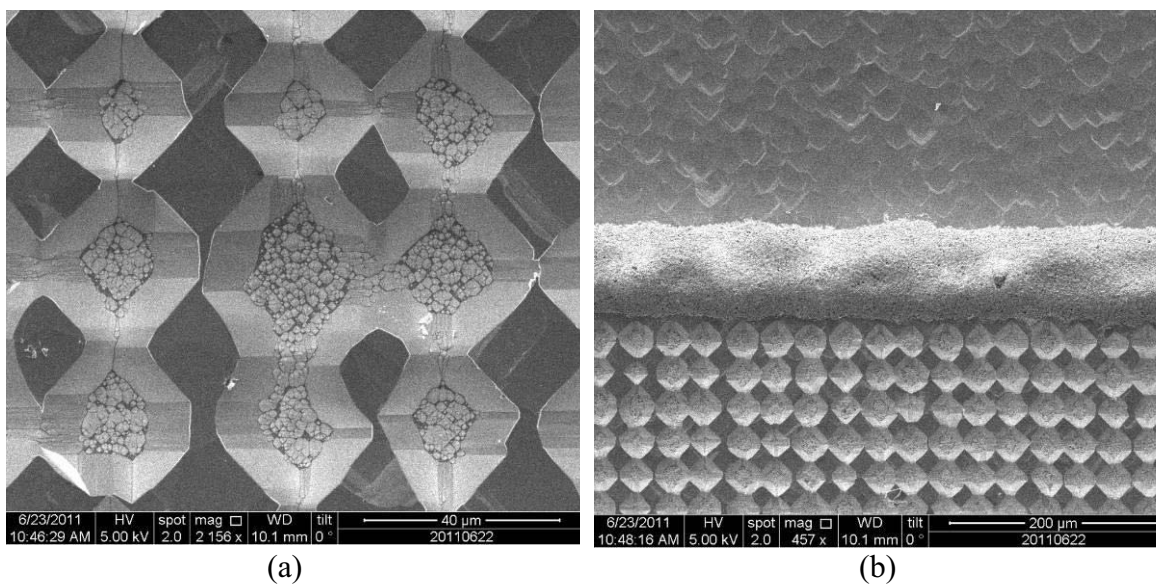


Figure 2. SEM micrograph Top view of the wafer with laser texturization. (a) The inverted-pyramid-like structure were fabricated by laser power : 17(watt). (b) Electrode and inverted-pyramid-like structure.

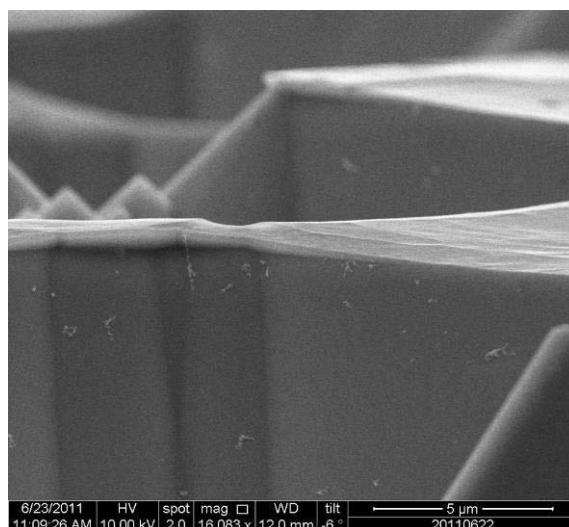


Figure 3. SEM micrograph cross-section of the wafer with ARC layer.

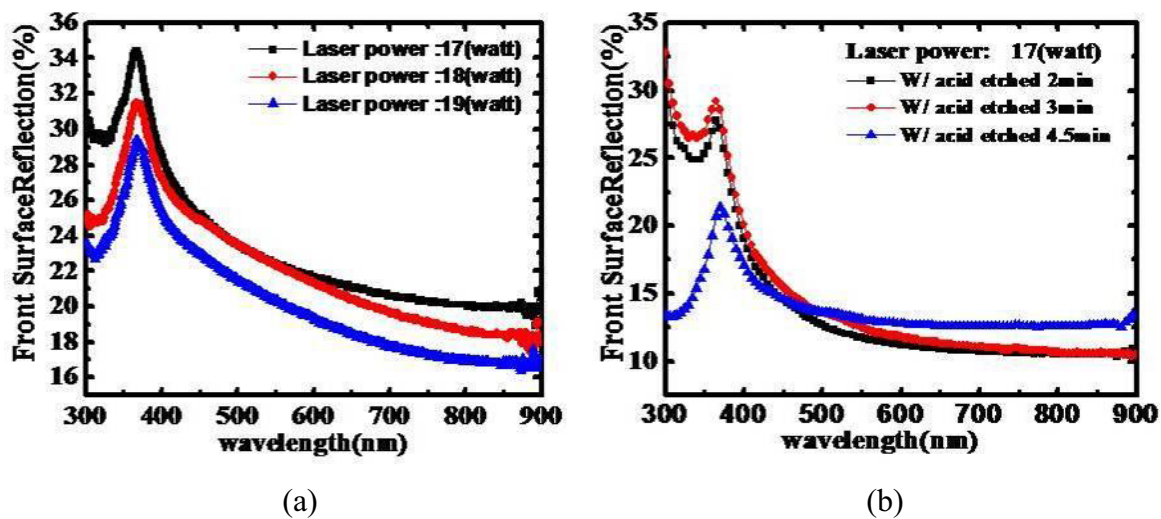


Figure 4. (a) Reflectance of the different laser power scribing (b) Reflectance of laser scribing at 17(watt), after removal of laser induced damage layer at different acid etching time.



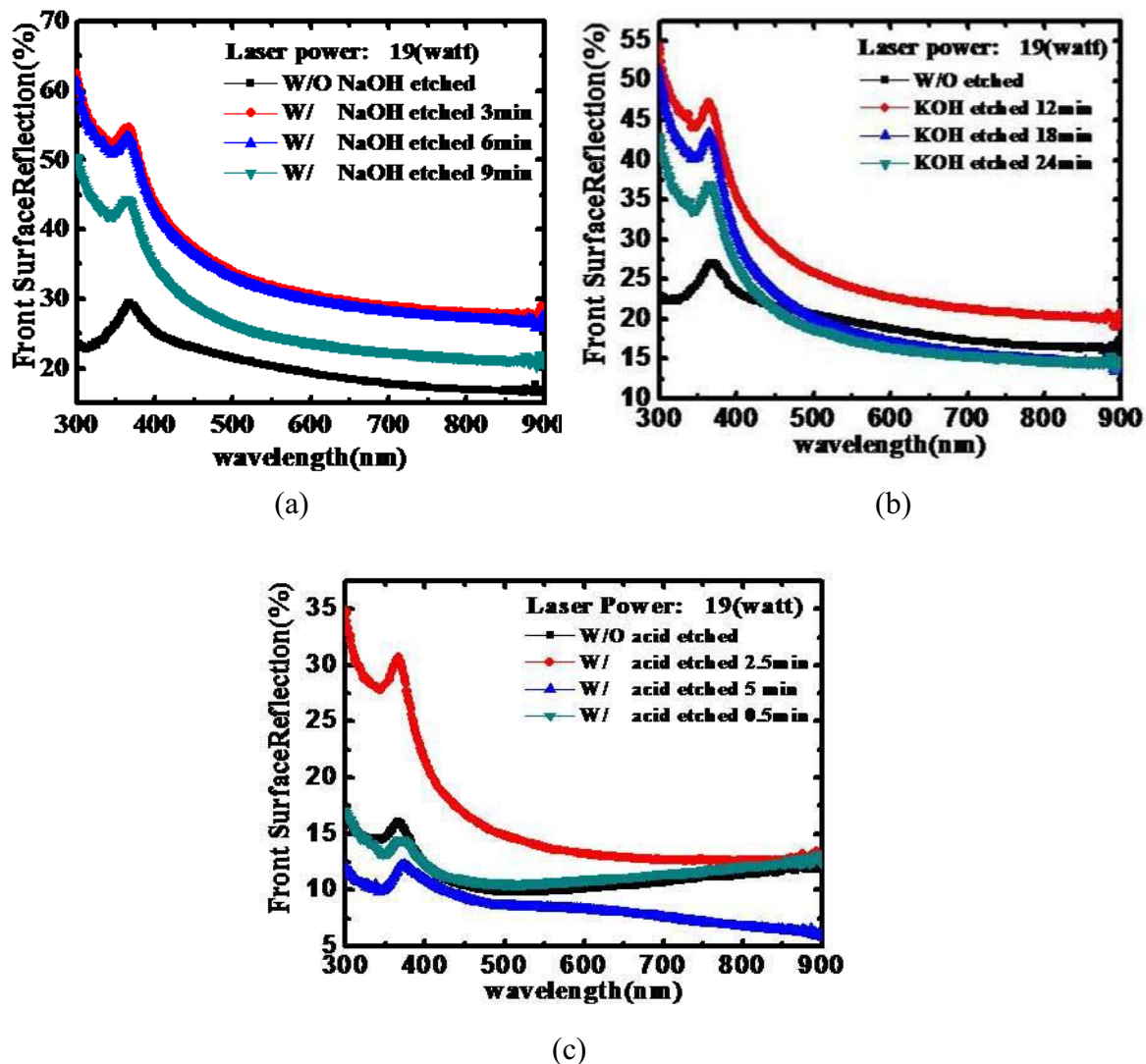


Figure 5. Reflectance of laser scribing at 19(watt), (a) with different NaOH solution etching time. (b) with different KOH solution etching time. (c) with different acid solution etching time.

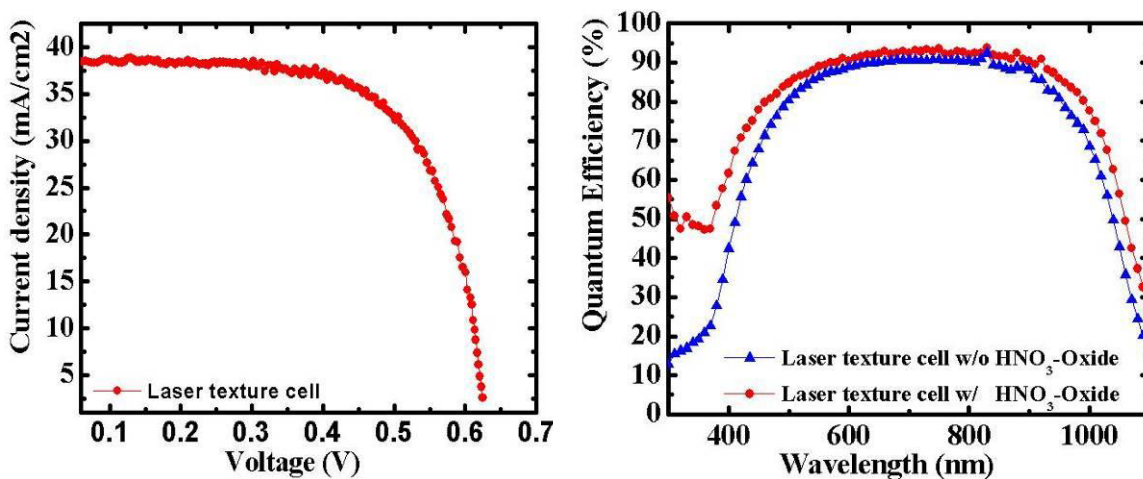


Figure 6. (a) IV characters of laser scribing at 17(watt), (b) Cell were passivated w/ or w/o HNO<sub>3</sub>-Oxide.

## Concluion

We attempt to investigate more stability, lower reflectance and easy processing inverted-pyramid structure by using laser technology. For the laser parameters, we control different laser power density, laser power frequency, laser power focus and laser power velocity in this experiment. From honeycomb to inverted pyramids-like structures, we used KOH solution to fabricate this structure.

## Acknowledgments

We are grateful for the support of this research by Green Energy & Environment Research Labs, Industrial Technology Research Institute (ITRI) and the Nano Facility Center, National Chiao Tung University.

## References

1. Kui-Qing Peng, et al, *Appl. Phys. Lett.*, 95, (2009)
2. J Zhao and MA GREEN et al., *Appl. Phys. Lett.*, 73, (1998)
3. AW Blakers et al., *Appl. Phys. Lett*, Vol 55 Iss 13, (2009)
4. L.A. Dobrzański et al., *AMME.*, Vol 29 Iss 1, (2008)
5. L.A. Dobrzański et al., *AMME.*, Vol 31 Iss 1, (2008)
6. JC Zolper et al., *Appl. Phys. Lett.*, Vol 55 Iss 22, (2009)