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Near Sub-Wavelength Texturization Of Silicon Surfaces For Solar Cell Applications

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Abstract*— Anti-reflection coatings (ARC) of dielectrics help in balancing the refractive index mismatch between silicon and air as result reducing the reflection losses but they do not cause bending of light rays which is essential for efficient light trapping of the injected light into the cell. Texturiaztion helps in both the reduction of reflection losses and light trapping due to bending of the light into a distribution of angles thereby increasing the path length of the light within the absorbing layer. In this paper, we report a simple process for texturiaztion of the silicon surface where the pyramid structures are near about sub wavelength structure (NSWS) but It overcome the contact problem due to nanoteturization. It is to be noted that this technique may well be used for both thick and thin silicon solar cells.

Keywords*—Texturization; IPA; Silicon; Solar cell; Near sub-wavelength structure (NSWS)

I. INTRODUCTION

High semiconductor reflectivity is one of the main causes for getting low solar cell efficiency. More than 30% reduction of efficiency for as-cut bare Silicon is only due to optical reflection losses. To reduce these losses quarter wave length layers of silicon oxide (SiOx), silicon nitride (SixNy) or titanium oxide (TiOx) with intermediate or gradient refractive indices are used as antireflec-tion coating (ARC)[1]. Texturization is one of the good technique for reducing the reflection losses. Gangopadhyay et al.[2] state that <100> oriented single crystal silicon wafers with textured surface and appropriate antireflection coating (ARC) has become a well-established method in photovoltaic industry for minimizing reflection losses. To minimize the reflection losses variety of other approaches have also been developed by modifying surface topography [3,4]. Surface texturization experiments of mono crystalline silicon (c-Si) using aqueous alkaline solution are observed by different researchers [1,4]. Electrochemical etching is another such approach to reduce reflection loss in the range of 5–8% by forming Porous silicon [5] .Selective etching of silicon of <100> orientation by using sodium hydroxide (NaOH) or potassium hydroxide (KOH) solution is also attractive and established method[6,7]. On the basis of surface topography different structure described by different researchers like as textured surface of nano size defined as sub wave length (SWSs) structure [8], moth-eye structures are also another types of topography to achieve the low reflecting silicon surface [9,10], etc. And different types of procedures are also introduced to achieve different topography like, reactive ion etching (RIE) to get perfect moth-eye structure [11], catalytic action of various metals(using Au layer reflection losses reduced to <5% [12]), nano imprint lithography technique for making 'Blac Silicon' has been developed [13-16]. In the black silicon or nano texturization technique we can reduce high reflection losses but at the same time it introduce different problems first of all it enhance the front surface area which is the cause of recombination losses, and another main problem arises is that due to arbitrary shape and size pores are formed in between metallic contact and cell which reduces the electron collection efficiency.

In this paper we have introduced the near sub wavelength structure (NSWS). NSWS are the structure where pyramids heights are average 800nm to 2000nm, and there no problem of taking contacts as well as it reduces the reflectance losses up to 6%.

II. EXPERIMENTAL DISCUSSION

- P-type mono crystalline wafer of <100> orientation with resistivity of 0.5-5Ω-cm are chosen for our experimental study. Before texturization we did some pre chemical treatment for better performance, first we degreased our sample by using iso-propyl-alcohol (IPA) and then Piranha etch to remove all dust particles. To remove native oxide we dipped the sample in 3wt% of hydrofluoric (HF) acid for 3 minutes and then ringed in deionized (DI) water.
- For saw damage purpose we use 8-10% sodium hydro oxide (NaOH) or potassium hydro oxide (KOH) for 2-5 minutes at 75^{o}c, then for getting more smooth surface we use isotropic chemical polishing agent (HNO_3:HF:CH_3COOH = 3:1: 1) at room temperature for 1minute again ringed in DI water.
- We use 1.8%-2.1 % NaOH and 8%-10% IPA at 83^{o}c for our texturization procedure, then we have observe the surface of wafer if babble stay on the surface then we have to add IPA again.

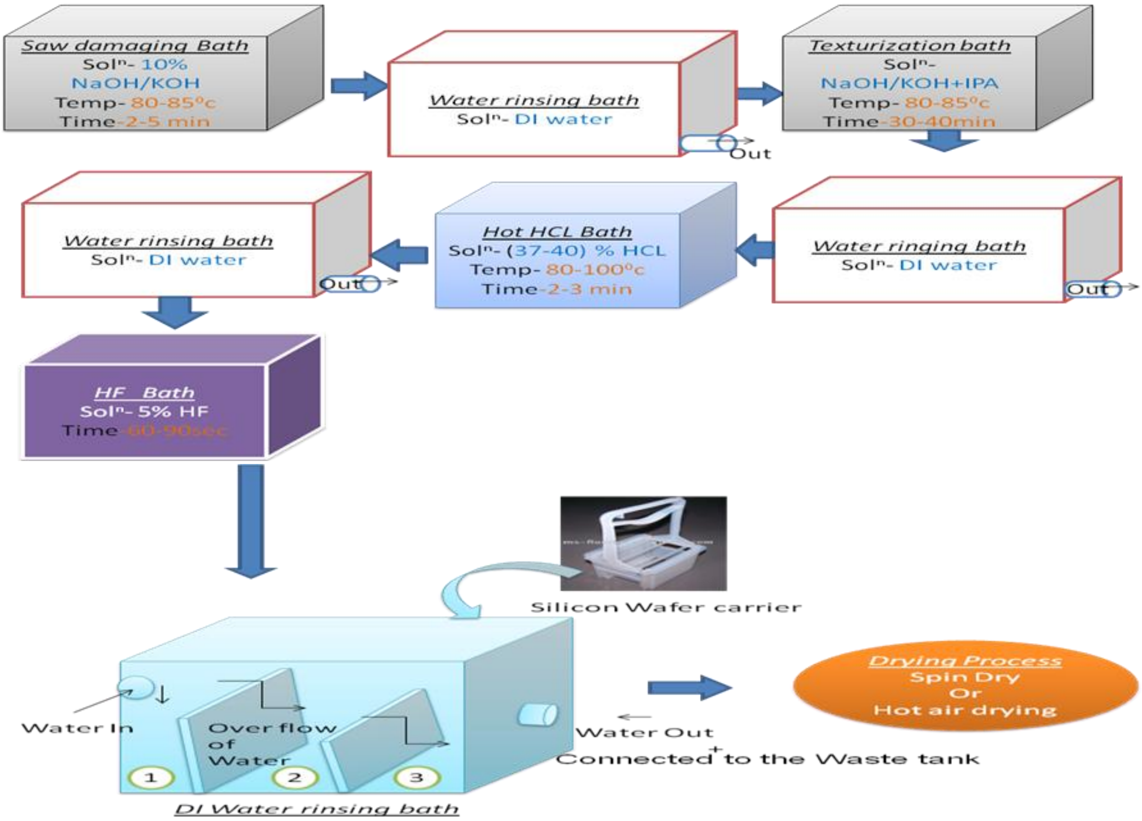

Fig. 1. flowchart of texturization process

- Since Na is a detrimental impurity in Si, we subsequently applied 37% Hcl solution at 60oc for 3 to 5 minutes then ringed in DI water.
- To remove unwanted Si dust and other particles we dipped the wafer in buffered HF for 25 to 30 sec followed by DI water ringing. For better DI water flow we have designed DI water bath as a different manner which shown in Figure- 1.

III. RESULTS AND DISCUSSION

We see in figure 2 that when light fall on the textured surface either it reflects many time at the surface or reflects back from the bottom of the cell and remain inside the cell. The no of reflection increases means that the probability of photon absorption inside the cell also increases.

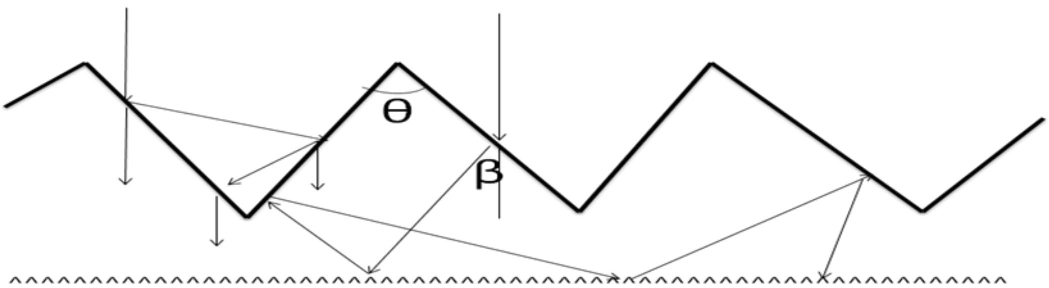

Fig. 2. Pictorial representation of optical path length enhancement

Now consider face/slat angle of created textured surface is θ where the path angle is β, cell thickness is d so at least light will travel the distance $D = \frac{d}{\cos\theta}$ inside the cell .If the fraction of light(f) leak out of the front surface at each impact which is depends on the absorption co-efficient α, as a whole effective absorption co-efficient α_T, and reflection co-efficient R. So the enhancement factor of the optical path length is defined by Gangopadhyay et al.[17]

$$m(\lambda) = \frac{\alpha_T}{\alpha} = \frac{1}{\cos\beta} + \frac{1}{\alpha d}\ln[\frac{1 - R(1 - f)e^{-4\alpha d})}{1 - R(1 - fe^{-2\alpha d})}]$$

Where we see that optical path length enhancement factor is mainly depends on reflection co-efficient, effective absorption co-efficient and the angle of the textured face θ.

We have studied different parameters during the texturization experiment. We have modified our three main experiment parameters like as time, concentration of solution, and some additional chemical which we have added at the time of experiments for getting better results. In figure 3 we see that by using 1.8% NaOH 3% CH3COONa solution mixture for 50 minutes we get better NSWS, but when we increase the time of experiments (duration 60 min) the chemical etched out the top of the hillock (Shown in figure 4) as a result again increase in reflectance.

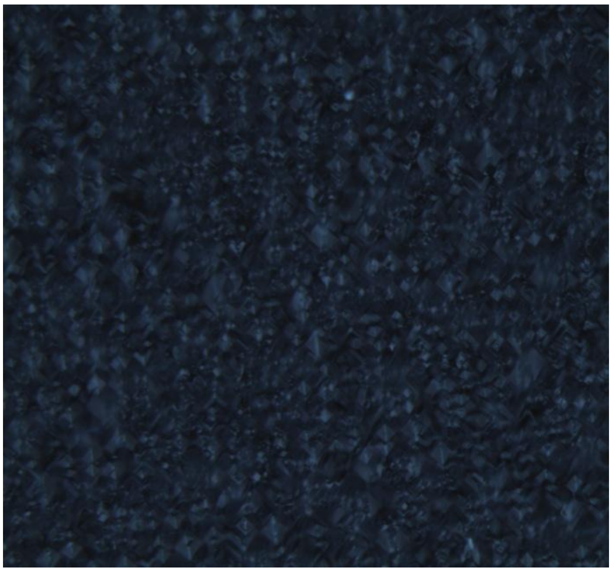

Fig. 3. For 50min texturization

Fig. 4. For 60 min Texturization

In figure 5 we have taken 8%NaOH for saw damage and 1.8% NaOH (additional 3% CH3COONa) and get better textured pattern where time taken 30 minutes, where we have to take care the concentration of IPA solution. In case of figure 6 we have taken 10% NaOH for saw damage and 3% NaOH (with 3% CH3COONa and IPA) for texturization for 50 minutes. We observed that the average 6 micron pyramid converted into near sub-wave length structure.

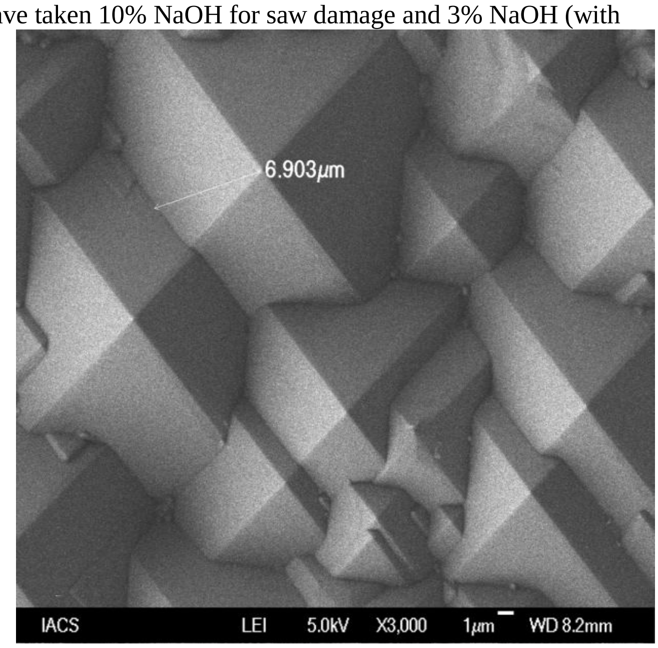

Fig. 5. For 30min texturization
(Sawdamage 8%, Texturing 1.8% of NaOH)

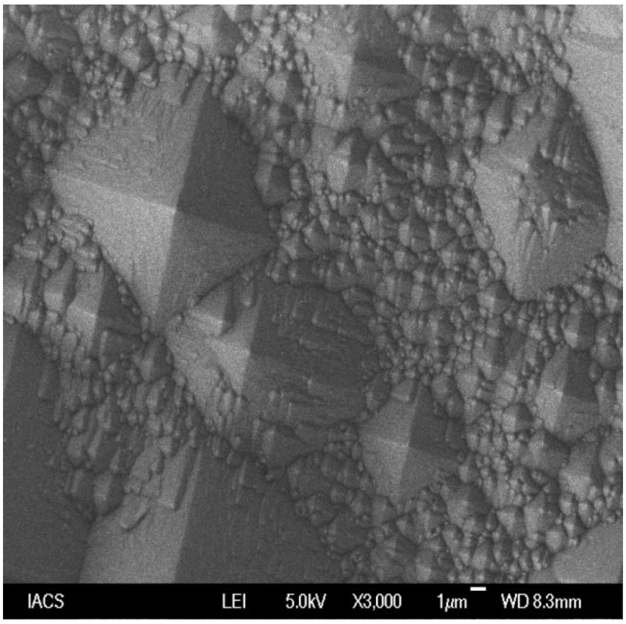

Fig. 6. : For 50 min Texturization
(Sawdamage 10%, Texturing 3% of NaOH)

When we measure the reflectance by using BENTHAM PVE300 Photovoltaic Device Characterisation System we observed that for 30 minutes sample (micro texturization) and 50 minutes sample (near sub wave length texturization) at 350nm light wavelength there are no significant change in reflectance but 400 nm to 650 nm there is 3% to 4% decrease in reflectance because no of pyramids increases for 50 minutes sample. After 800 nm of light wavelength penetration is high and again there is a high probability of back side reflection as a result we get less reflectance or higher optical path length within this region of wave length (shown in figure 7). So we can use these types of near sub wave length structure to increase the light absorption efficiency for getting higher solar cell efficiency.

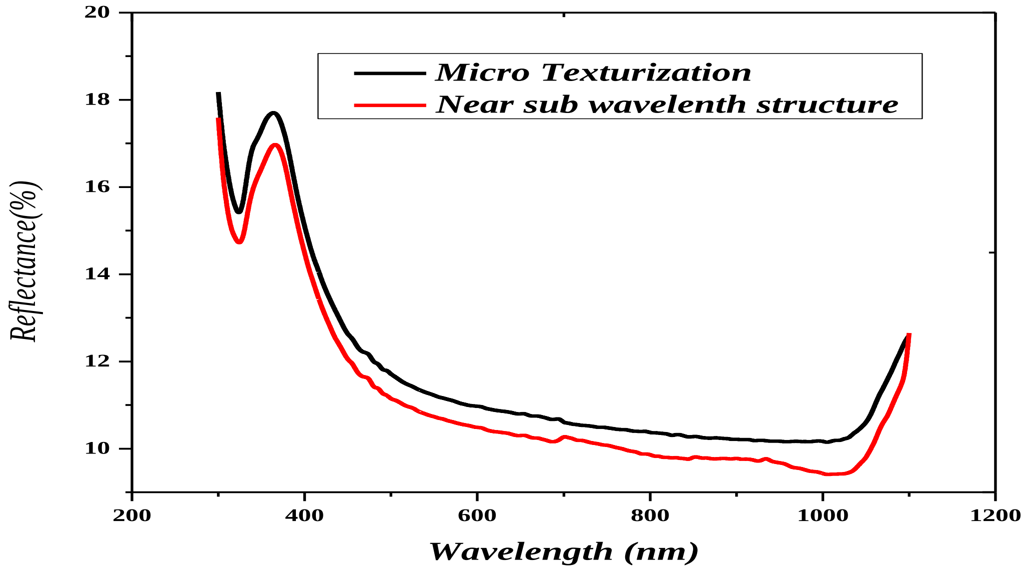

Fig. 7 . Reflectance changes due to different solution concentration and different time

IV. CONCLUSION

We have investigated the micro texturization technique which is already established in industry for mono crystalline silicon solar cells but we change some parameter and found a new structure of micro texturization where pyramid structure is near to sub wave length structure but by these structures we can overcome the contact problem (regarding black silicon surface) and also got better reflectance result than the micro pyramid structure. We are also investigating to control the process by which we can able to gate better performance reflectance than black silicon.

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