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Antireflection Coating Thickness Control for Silicon Solar Cells using Confocal Microscopy

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Abstract: Multicrystalline silicon solar cells are one of the most commonly available solar cells worldwide. These cells have concave etching pits on the front surface as texturing features that are further decorated by the deposition of the antireflection coating (ARC) on solar cells. Several process control measures are available for texturing such as etch depth measurement or inline reflection sensors but subtle topological variations are allowed within the process limits which produce variations in the final product related to current output and appearance. Whereas most of the methods are focused on the texturing process, the ARC process can also be finely controlled with respect to texturing batches to nullify such variations. We propose the use of a rapid and sensitive method of confocal microscopy to parameterize the surface topology of the textured wafer and control the antireflection coating to maintain a uniform efficiency and appearance of the solar cells. As the measurement and analysis time is of the order of seconds, the technique can also be used for inline sampling for controlling the antireflection coating thickness.

Index terms: Silicon solar cell, confocal microscopy, surface topology, surface roughness, developed interfacial area ratio

I. INTRODUCTION

Front texturing and the deposition of antireflection coating (ARC) are the key features of the fabrication of a solar cell for enhancing the light absorption. The deposition of ARC gives the solar cells its characteristic blue appearance. Any variation in the quality of texturing or ARC produces not only the power output variation but also changes in solar cell appearance. Since solar cells are assembled together into the solar modules, the uniformity in the appearance of the solar cells is a desirable feature for aesthetics reasons and adds value to the product.

Even slight variations in the overall texturing can change the thickness of ARC and the solar cell appearance because the color of the solar cell is decided by the thickness of ARC. The thicker ARC produces a light blue color whereas thinner ARC produces rich blue to purple hue (Fig. 1). This is because ARC is deposited as a conformal coating and the variations in the total surface area due to texturing process changes the material available for maintaining a thickness value. Since ARC only accentuates the texturing variations, the prior batch-wise detection of such texturing variations can be used to tune the ARC deposition process.

The common methods for detection of texturing quality are the etching depth measurement and sensing the laser beam(s) reflection from the textured wafers. Scanning electron microscopy (SEM) and laser scanning microscopy (LSM) has also been reported for process development, but the treatment is qualitative in nature and cannot be used to industrial process control [1][2][3]. We propose the use of a sensitive and quantitative method of confocal microscopy to differentiate the texturing i.e., the increase in surface area from the roughness of the surface. We have seen that the ARC variation is explainable by the texture rather than the surface roughness values. Such detection of texturing can be used for both controlling texturing and, prior to the deposition of ARC, to finely tune the deposition timing and produce uniform appearance of the solar cells independent of the unwanted but unavoidable variations in the texturing process.

II. SOLAR CELL PROCESSING

Solar cell texturing process increases the surface area on the incident side of the solar cell. This helps in light absorption by having more area available for the absorption of light and increased opportunities for internal reflections. During texturing, a combination of horizontal and vertical etching by the chemicals provide the etch depth and the texturing to the wafer. Any change in the chemistry, chemical bath temperature or wafer surface can introduce difference in the texturing quality. Novel approaches such as ion chromatography and measurement of chemicals' physical parameters have been reported for inline process control [4][5][6]. Another inline process control tool for texturing is based on the reflection of laser beams from the textured wafer. But the common practice to control the variations in the texturing is the measurement of the etch depth [7]. Even though the etch depth and the texturing quality are related, more etch depth does not ensure more texturing. Thus, an optimum depth is maintained for a given chemistry as a crude but simple measure to get the desired texturing effect.

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After texturing; impurity diffusion, single side etching and phosphosilicate glass (PSG) removal is carried out. The next process is the deposition of Antireflection coating (ARC) in a vacuum chamber using plasma enhanced chemical vapor deposition (PECVD) method. PECVD deposits a conformal coating of about 80 nm of silicon nitride (SiN_x) on the features produced by texturing process. Since ARC thickness is usually controlled by the deposition time for the process, the thickness of the PECVD coating is very sensitive to the actual change in the surface area produced by texturing. If the surface area of the wafers decreases due to reduced texturing, ARC for a given deposition time will be relatively thicker and vice versa. So, it is the combined effect of texturing and ARC that decide the light trapping and appearance of the solar cells. As the optimum thickness of ARC is critical for the solar cell design, these thickness changes compromise the efficiency of the device as well.

III. CONFOCAL MICROSCOPY

Confocal microscopy or confocal laser scanning microscopy (CLSM) is a technique to study the topology of the surfaces by using the interference between two incident laser beams reflected from the surface. With the optical resolution of the order of nanometers, it can provide a detailed map of a section of the wafer surface in three dimensions and enables the numerical estimation of various surface parameters. With such estimations, direct measures of the surface topology can be obtained in contrast with the other indirect methods mentioned earlier (Section II). The common surface and height parameter derivable from the CLSM images are arithmetic mean height or average roughness(S_a), root mean square roughness (S_q) and interfacial area ratio (S_{dr}) etc. Table 1 summarizes various surface parameters and their description for comparison purposes. The use of CLSM parameters have been reported earlier for solar cell texturing process, but as a qualitative tool in regard with parameters S_a and S_q [8]. But these height parameters capture the extent of vertical etching into the wafer. This may not necessarily capture the effectiveness of texturing. The desirable texturing will produce uniform undulations that maximize the surface area without producing deep features which cause shunt failures and recombination losses [9]. It is argued here that the desirable texturing is measured by S_{dr} which measures the increase in the surface area over the ideal flat plane. S_{dr} can differentiate surfaces of similar roughness and increases as spatial intricacy or texture is increased. Reference [10] mentions S_{dr} along with S_a for studying the texturing process. It was also observed that etch depth is not a good measurement for diamond cut silicon wafers as no correlation was observed between etch depth and S_{dr} [10]. This implies that the control of ARC over the texturing control which is implemented using etch depth method can bring significant process improvements. Here we have used CLSM and S_{dr} measurements for tuning ARC rather than texturing process. As the industrial practice of using etch depth is not sensitive to the detailed topology, CLSM can provide an additional measure to insulate ARC from variations in the texturing process.

Table I Commonly used areal parameters used to describe the surface properties.

Parameter	Numerical expression	Description
Maximum height (S_z)	$S_z = \max(x,y) + \min(x,y)$	Maximum height (peak to valley) of the areal surface defined by x, y coordinates
Average roughness (S_a)	$S_a = \frac{1}{A}\iint \lvert Z(x,y)\rvert dxdy$	Average roughness evaluated over the complete 3D surface. Z is the height parameter. A is the total scanned area
Root mean square roughness (S_q)	$S_q = \sqrt{\frac{1}{A}\iint Z^2(x,y)dxdy}$	Root mean square roughness is equivalent to the standard deviation in the peak heights.
Developed interfacial area ratio (S_{dr})	$S_{dr} = \frac{1}{A}\left[\iint\left(\sqrt{\left[1+\left(\frac{\partial z(x,y)}{\partial x}\right)^2+\left(\frac{\partial z(x,y)}{\partial y}\right)^2\right]}-1\right)dxdy\right]$	Additional surface area contributed by the texture as compared to an ideal plane the size of the measurement region

IV. EXPERIMENTS AND ANALYSIS

The analysis of texturing and ARC thickness control using CLSM was carried out on the slurry cut multicrystalline wafers, but the approach is a generalized one. The texturing was carried out in inline tool by Rena® using HF: HNO3 mixture. The variation in texturing producing different ARC colors shown in Fig.2 was produced by the variation the chemical composition of the bath. ARC deposition was carried using PECVD tool by Centrotherm®. Single layer ARC was used for all the samples used. CLSM measurements were carried out on Zygo® optical profiler with lateral range of 166 micrometers, vertical resolution of 0.1 nm and lateral resolution of 0.5 micrometers. The thickness of ARC was measured on single wavelength ellipsometer by Sentech Instrument Gmbh.

Fig. 2 shows the relation between the short circuit current (Isc) of the solar cells and the thickness of the ARC. The samples are drawn from two batches with different texturing parameters (Texture A and B). It is seen that the ARC thickness and texturing together decide Isc of the device. The difference in texturing evident in Fig. 3 even in solar cells can be parametrized for process optimization by measuring the texturing using CLSM. It may be noted a nanometer-scale ARC is deposited on the micrometers-wide texturing structures. So the topology of the texturing features is still available for inspection even after ARC deposition.

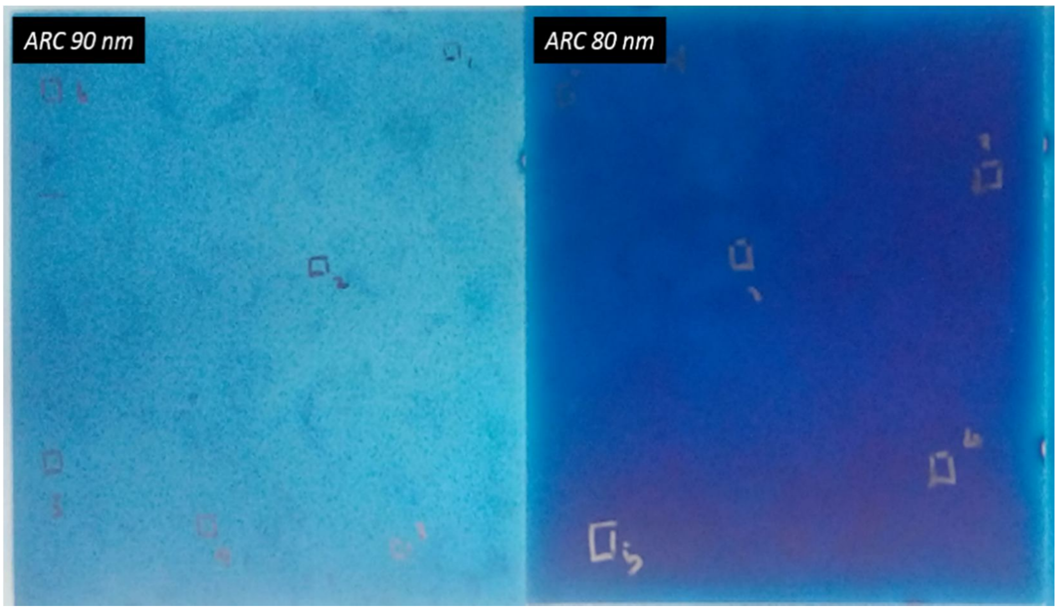

Fig. 1 The ARC thickness of two wafers with same ARC parameters but different texturing. The variation in color is caused by the difference in underlying texturing. The marked areas are for taking the CLSM and ellipsometric measurements at the same spot.

To investigate the effect of texture on ARC, various wafers with different texturing and identical ARC deposition parameters have been used. Etch depth for all the batches were in 2.0 µm-2.6 µm range. The etch depth for each individual sample was not measured. CLSM measurements were carried out on 3 – 4 points on the wafers identified with their x-y position on the surface. Fig. 3 shows grey scale image from 50x microscope from CLSM setup and the 2D projection created for parameters estimation of a typical surface mapping for a textured silicon wafer. The local area mapped in 3-D were used to calculate average roughness (S_a) and developed interfacial area ratio (S_{dr}). After that, ARC was deposited on the wafers and the local ARC thickness measurements were also carried out using ellipsometric measurements at the same spots marked earlier. Fig. 4 shows the relationship between the ARC thickness and the CLSM parameters. Fig. 4(a) shows the ARC thickness does not have a strong relationship with height parameter S_a whereas in Fig. 4(b), a clear relationship between S_{dr} and ARC thickness value is evident. S_a and S_{dr} have been calculated from the same CLSM measurements. When the value of S_{dr} is low indicating less texturing, the ARC layer is thicker because the reactive molecules available for deposition during the plasma conditions have lesser area for deposition, so they stack vertically for thicker films. On the other hand, when the S_{dr} value is high, the available molecules need to spread thinner to cover a larger area. As the plasma is on for the same time for both the cases, the total thickness of the ARC layer decreases for higher S_{dr} values. It is seen that S_{dr} provides greater sensitivity for ARC process control than the roughness parameter S_a and can be used as a process control parameter.

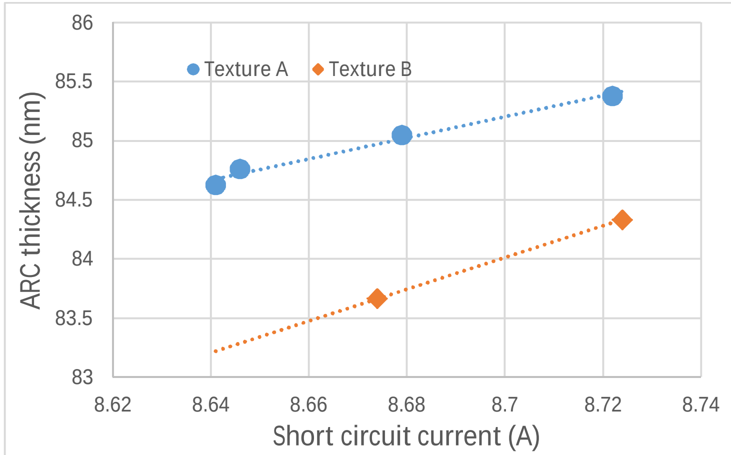

Fig. 2 The variation in the short circuit current (Isc) of the solar cells with ARC for two different texturing conditions. Both ARC and texturing contribute to the solar cell Isc values.

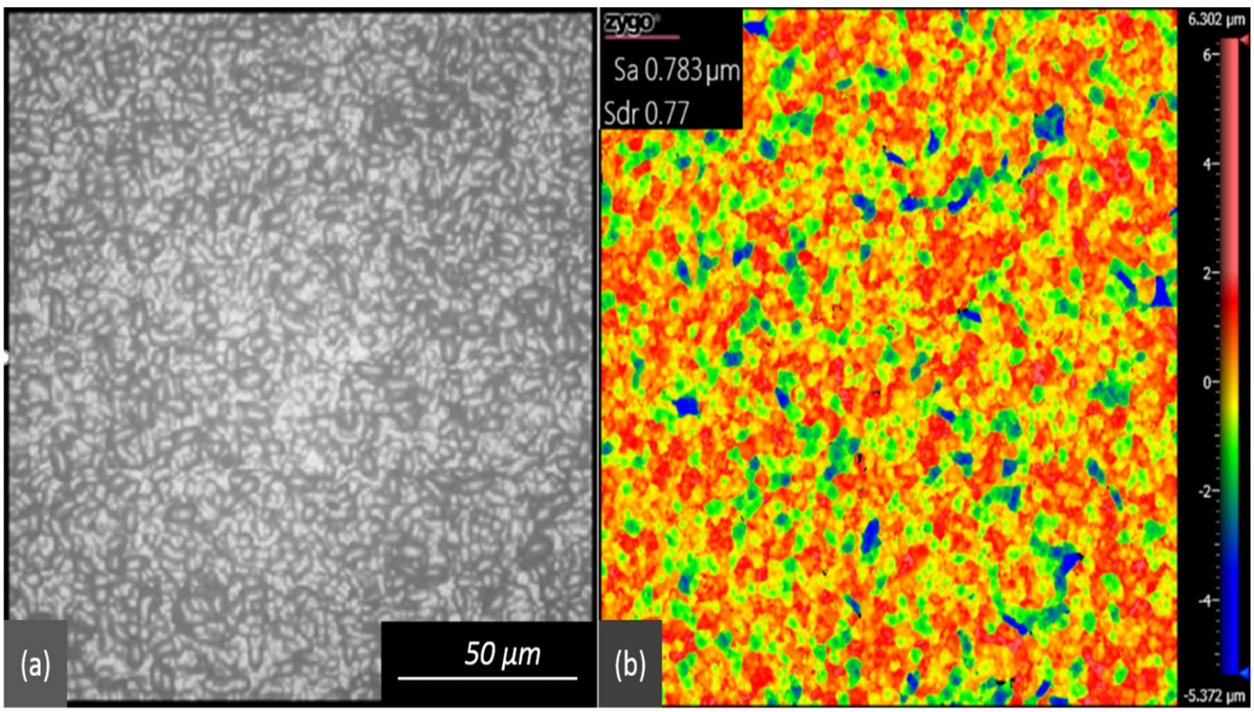

Fig. 3 (a) Grey scale image (50x resolution) of textured surface produced by CLSM setup and (b) Color map of texture for image processing and extraction of areal parameters.

From Fig. 4(b), the difference of 0.2 in S_{dr} value can cause the ARC thickness change of about 5 nm in the ARC thickness. This is very significant and can completely change the solar cell appearance and efficiency. Since the deposition rate of ARC is ~ 0.5 nm/sec, the thickness can be batch-wise controlled by changing deposition time by 12-13 seconds for every 0.1 change in S_{dr} from a reference value.

A proposed method is to sample a wafer every batch (usually 1000 wafers) and compare S_{dr} with the baseline value. Using the relation in Fig. 4(b), the expected thickness can be estimated. The single measurement and image processing time for CLSM is 10-12 seconds where the ARC process time is around 40 minutes. So the expected variation can be ascertained well in time for the next batch and the deposition time can be varied to control thickness. This would nullify the variation in thickness and produce uniform appearance across batches. It can also nullify the ARC changes with the texturing chemical bath age.

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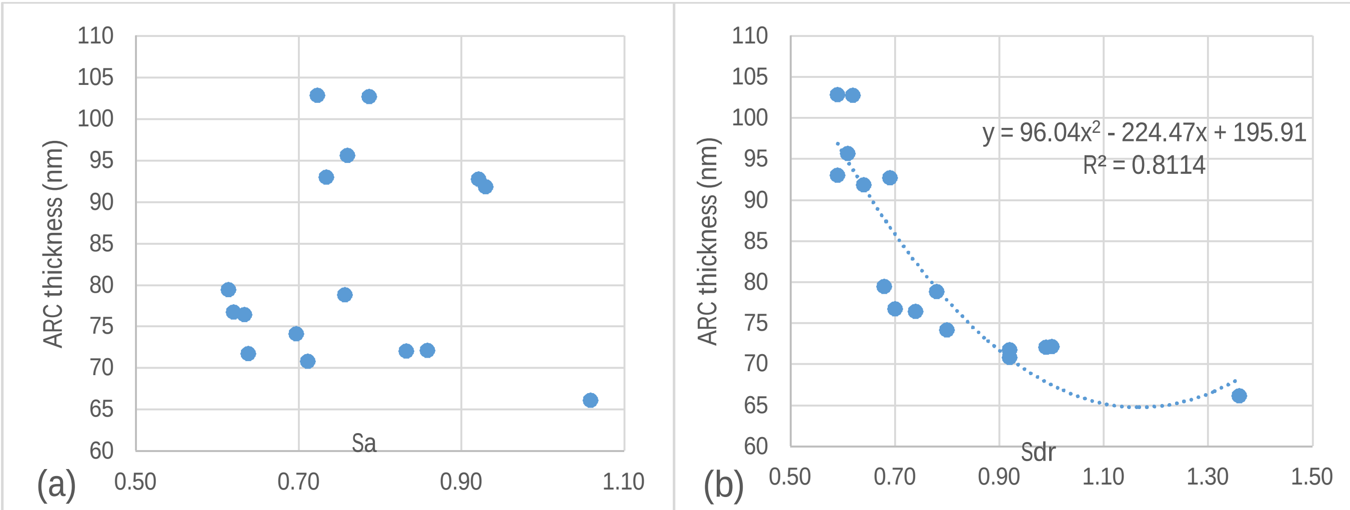

Fig. 4 The relationship of the ARC thickness with the areal (3D) parameters derivable from CLSM measurement. (a) ARC thickness shows poor relation to the measured average roughness (S_a) (b) ARC thickness and interfacial area ratio (S_{dr}) shows trend that can be exploited to predict ARC thickness. S_a and S_{dr} have been calculated from the same measurements.

V. CONCLUSION

We have established interfacial area ratio (S_{dr}) as the relevant parameter for measuring the texturing for ARC process control. This enables the process engineer to fine tune the deposition time of the PECVD deposition for antireflection coating for each and every batch. The application of this technique will result in nullifying the effect of minor variations in texturing process to produce consistent current and color for all solar cells thereby enhancing the aesthetic appearance of the solar modules.

VI. ACKNOWLEDGEMENT

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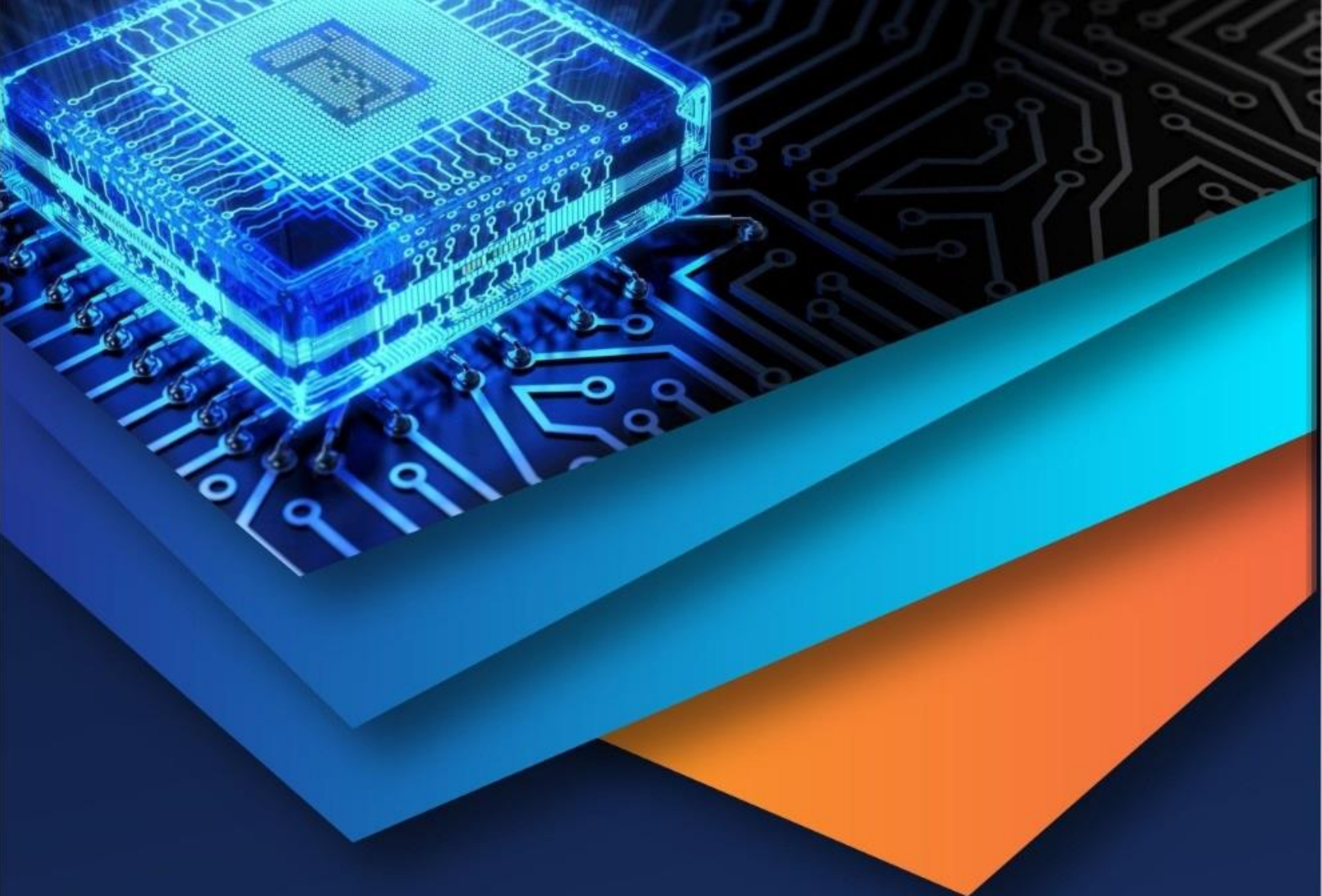
REFERENCES

[1] M. Lippold, S. Patzig-Klein, E. Kroke, “Fundamental studies of acidic wet chemical etching processes: Acidification of HF-HNO_3-H_2O etching mixtures”, 24th European Photovoltaic Solar Energy Conference, Hamburg, Germany, pp. 1751-1753, 2009.
[2] Marcus Lippold, Sebastian Patzig-Klein, and Edwin Kroke, “HF-HNO3-H2SO4/H2O Mixtures for Etching Multicrystalline Silicon Surfaces: Formation of NO2+, Reaction Rates and Surface Morphologies”, Zeitschrift für Naturforschung B, vol. 6, issue 2, 2014.
[3] Yuang-Tung Cheng, Jyh-Jier Ho, Song-Yeu Tsai, Zong-Zhi Ye, William Lee, Daw-Shang Hwang, Shun-Hsyung Chang, Chiu-Cheng Chang, Kang L. Wang,” Efficiency improved by acid texturization for multi-crystalline silicon solar cells”, Solar Energy vol. 85, pp. 87–94, 2011.
[4] Antje Oltersdorf, Martin Zimmer, Martin Seitz, Jochen Rentsch,” Analytical research of the acid etching bath by ion chromatography”, 23rd European Photovoltaic Solar Energy Conference and Exhibition, Valencia, Spain, pp. 1488-1492, 2008.
[5] M. Zimmer, A. Oltersdorf, J. Rentsch, "Online process control of acidic texturisation baths with ion chromatography", *Talanta*, vol. 80, no. 2, pp. 499– 503, 2009.
[6] L. Mohr, T. Dannenberg, M. Zimmer, J. Rentsch, “Alternative inline analysis of acidic etching baths”, 32nd European Photovoltaic Solar Energy Conference and Exhibition, Munich, Germany, pp. 929-934, 2016.
[7] A. Hauser, I. Melnyk, P. Fath, S. Narayanan, S. Roberts, T.M. Bruton, “A simplified process for isotropic texturing of mc-Si”, IEEE, 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan, vol. 2, 2003.
[8] Katrin Kriega), Niko Jenek and Martin Zimmer, “Texturization of Multicrystalline DWS Wafers by HF/HNO_3/H_2SO_4 at Elevated Temperature”, AIP Conference Proceedings 1999, 050004 (2018); https://doi.org/10.1063/1.5049294
[9] P. Panek, Marek Lipinski, J. Dutkiewicz, “Texturization of multicrystalline silicon by wet chemical etching for silicon solar cells”, Journal of Materials Science 40(6), pp. 1459-1463, March 2005
[10] Marcus Lippold, Florian Buchholz, Christoph Gondek, Florian Honeit, Eckard Wefringhaus, Edwin Kroke, “Texturing of SiC-slurry and diamond wire sawn siliconwafers by HF–HNO_3–H_2SO_4 mixtures”, Solar Energy Materials & Solar Cells, vol. 127, pp. 104-110, 2014



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