Direct Etch through SiNx, Selective Dope, and Seed Layer Dispense with Inert Piezoelectric Inkjet Print Head for Solar Cell Fabrication

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Abstract

The solar photovoltaic industry is driven towards increasing cell efficiency while reducing cost. Ink jet process offers an attractive, non-contact method enabling reduced capital equipment cost, fewer process steps and higher throughput. This study focuses on inkjet processes development of directly etching through a Silicon Nitride layer (anti-reflection layer), selectively doping and precisely dispensing a seed layer, also their combination at a shot to prepare for conventional screen printing afterwards or for low cost electroplating for the "selective-emitter" solar cell fabrication.

Introduction

Piezoelectric inkjet technology is being tested, evaluated and used to replace traditional manufacturing processes in three main industries - flat panel display, printed electronics, and solar cells due to (1) efficient material usage (cost saving and environmentally friendly), (2) direct write process (an additive process), (3) speedy set-up (digital printing and no masks needed), (4) large area printing, (5) high productivity by increasing number nozzles and jetting frequency, (6) non contact printing for sensitive substrate, (7) print heads and jetting materials tailored for specific applications and (8) ultimately low capital investment. Trident has involved those areas and developed ink jet print head technology for applications [1-3]. As a result, LCD industry has adopted ink jet processes for mass production from generation 6 to generation 10.

Recently, SEMI Group has published solar industrial trend for next ten years. It indicates that the solar industry is driven to processes other than screen printing to reduce contact width and shadowing (figure 1) and to replace expensive silver contact with less expensive electroplated copper (figure 2). In response to solar industry needs, Trident and Cookson have developed unique combinations of inert ink jet print heads (figure 3) and jettable, functional materials to prepare both screen printing and plating of metal contacts for selective emitter solar cell fabrication. Such innovation has potential to result in significant reduction in wafer production costs and increases in cell efficiency benefiting the solar cell provider as well as the consumer.

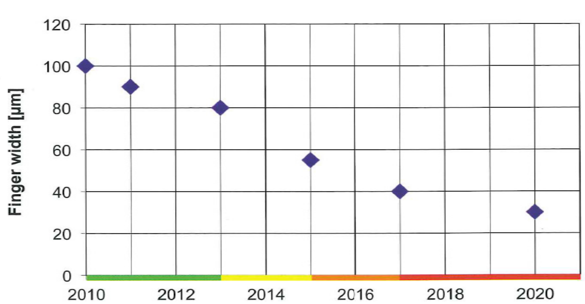

***Figure 1**. Finger Width Decrease over Time (Year)*

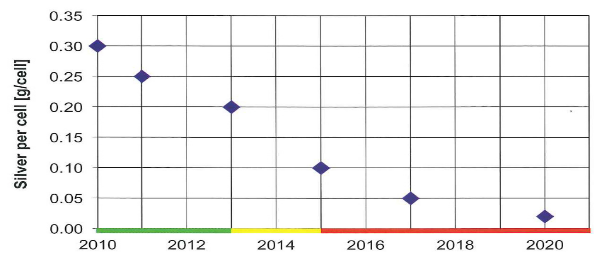

***Figure 2**. Silver per Cell Decrease over Time (Year)*

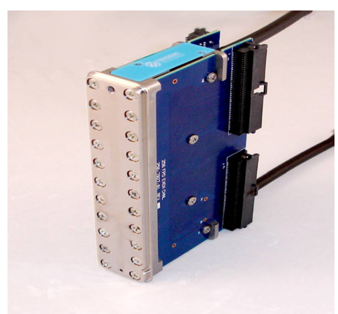

***Figure 3**. Inert Piezoelectric Ink Jet 4" Print Head (256Jet-S)*

Ink Jet Process for Selective Emitter

Selective emitter approach presents heavily doped regions underneath the metal grid and lightly doped regions between the metal grid. Its predicted 0.3% efficiency increase could be from a low contact resistance due to heavy doping underneath the metal grid, improved front-surface passivation of the lightly doped region between the grid and reduced recombination under the metal contact. The current approach by Laser doping process creates surface damage. Therefore, proposed is ink jet process which is detailed below will address the shortage. The following process also related to jettable, functional and aggressive materials. However, 256Jet-S print head is inert enough to last for one year under industrial operation.

Combined Etchant/Dopant for Screen Printing

Etching of the SiNx ARC (Anti-Refection Layer) layer – The SiNx layer must be completely removed directly under the front contact areas. This enables a good bond with reduced contact resistance. Trident- Cookson rely on an Etchant " VersaEtach-S" to be pattern jetted on to the SiNx and to etch through the layer down to the emitter when exposed to increased temperatures of up to 375^{o}C, Through this method features can be etched accurately with width of 50-100um (figure 4).

Selective Doping – The wafer is then heated up to 800^{o}C and the n-dopant ions contained in the VersaEtch-S penetrate into the bare silicon emitter, improvement shows in ohmic resistance reduction creating a ++ dopant selective emitter area directly under the metallic contact region preparing it for screen printing of the silver contacts.

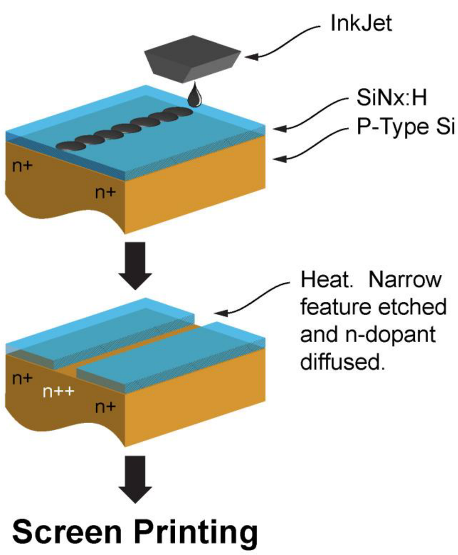

***Figure 4**. Ink Jet Etchant & Dopant "2 in 1" for Selective Emitter*

Combined Etchant/Dopant/Seed Layer for Plating

In another Cookson offering, "VersaEtch–P" a thin, palladium seed layer is also jetted along with the etchant and the dopant components of the fluid. In a third function to the above VersaEtch-S process the palladium creates a thin film silicon emitter and prepares the surface for plating (figure 5).

During plating the wafers are exposed to baths of nickel, copper and tin to plate up the contact lines to the desired height vs. width ratio. These metallic plated contact lines are " silver free" resulting in less than 1/5 the cost of silver. The plated contacts are also free of the screen paste glass frit and more homogenous than the silver screen contacts. The expected result is up to 1% efficiency improvement from the plated contacts compared to screened contacts.

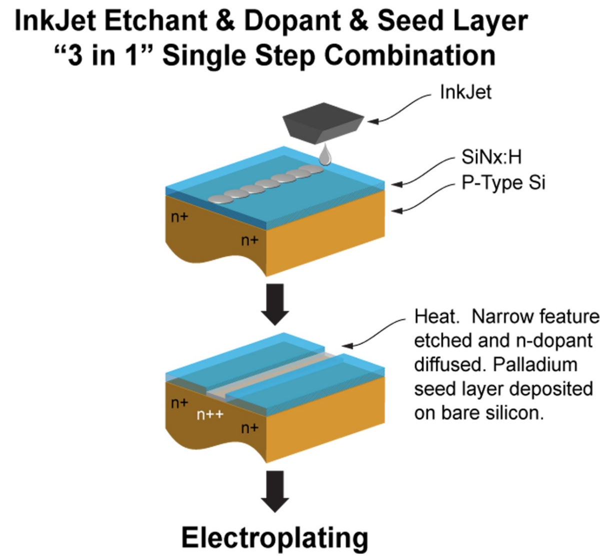

***Figure 5**. Ink Jet Etchant/Dopant/Seed Layer "3 in 1" Combination for Selective Emitter*

Experiment and Result

Before following the above Schemes, printing system was configured using Pixdro LP-50 with Trident 256Jet-S print head inside as shown in figure 6. The etchant/dopant jetting material (VersaEtch-S) was selected. In order to control etched line width on multi-crystalline silicon wafers processed with PECVD SiNx previously, the study on the variation of etched line width was conducted against various drop volume and various printing DPI (Dots Per Inch). Figure 7 showed that for given drop volume, the line width linearly increased when DPI increased and that the line width increased when drop volume increased.

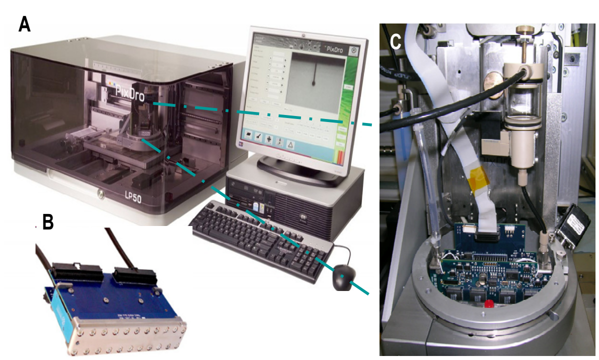

***Figure 6**. Printer Setup*

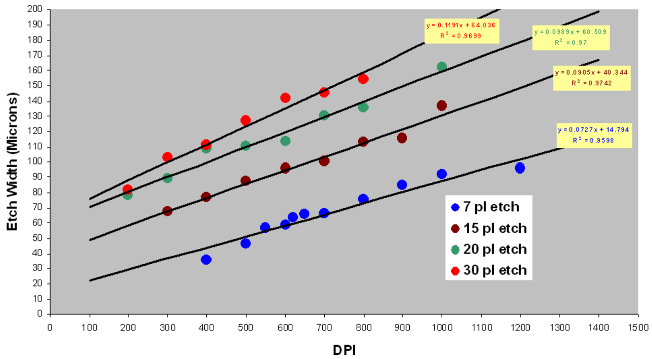

***Figure 7**. DPI vs Etched Line Width*

To understand the effectiveness of etching process, four PECVD SiNx processed silicon wafers were printed at 550 DPI using a 7pl print head for AES (Auger Electron Spectroscopy) analysis. AES Mapping and AES point mode were performed on these four samples. AES mapping clearly shows that Nitrogen was not present on the etched line but was on the none-etched area. AES point mode also shows no Nitrogen was detected on the etched line. Figure 8 showed that the average line width was 53um and that Nitrogen concentration on the etched line was absent.

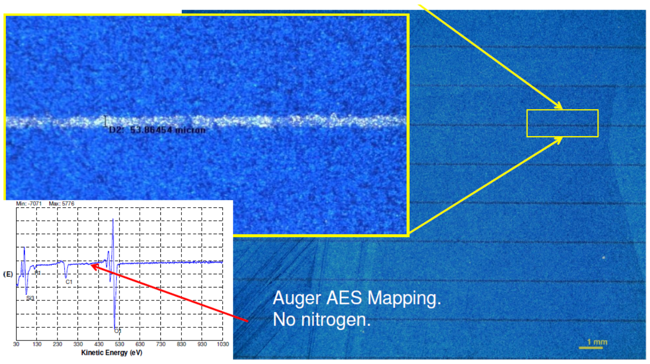

***Figure 8**. Etched Lines and AES Analysis*

Conclusion and Future Work

Tiny amount of Palladium can be added into "VersaEtch-S" and turns it to "VersaEtch-P" without changing ink jet and etch behavior. Trident continues to work towards final solar cell efficiency measurement. Ink jet process can potentially match the enhanced cell efficiency 0.5% of other selective emitter approaches. It advantage and benefit may include 1) that single-formula jetting material consists of etchant, dopant and seed layer; 2) that etched line width is demonstrated about 53 um; 3) that as a non-contact process, ink jet process can result in up to a ten times reduction in costly wafer scrap compared to the use of contact selective emitter processes such as screen etching or laser etching and 4) that combining the etching , doping and seeding processes also eliminates the need for very precise alignment.

Acknowledgement

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References

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Author Biography

Ty Chen received his Ph.D. in Mechanical Engineering from University of Wisconsin at Milwaukee. He works as the Head of Engineering at Trident, an ITW company. His work has primarily focused on piezoelectric and other actuators, MEMS processes, and inkjet print head design and analysis for emerging markets. He is a member of IS&T