MONOCRYSTALLINE SILICON TECHNOLOGY OF THE FUTURE – SLIVER MODULES

Hana Benešová

Department of Electrical Power Engineering and Ecology, University of West Bohemia

ABSTRACT

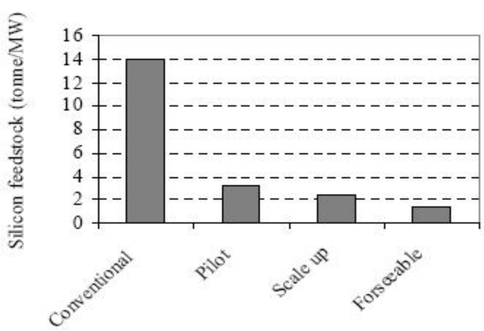
Problems of the photovoltaic cells becomes more and more topical in connection with sharply rising prices of the electrical energy and thus the new technology of solar cells produce are invented. This paper is focused on problematic of one of the new trends in the photovoltaic cells sphere – on the Sliver technology. This is the monocrystalline silicon technology which reduce the silicon usage and thereby the cost of the photovoltaic cells. The technology could have decreasing the silicon feedstock requirements to 1 tonne per MW. On top Sliver cells are great at high performances characteristic, e.g. high efficiency, high open circuit voltage, near lambertian light trapping, very good tolerance of varying material quality, etc. The first part of this paper is dedicated to the Sliver technology generally. The concept of the Sliver photovoltaic cells, texturing method, most important Sliver cell design and IV curve are presented here among others. In the second part I deal with the Sliver modules. There are described the principle of the modules, most important performance, e.g. low operation temperature, low temperature coefficient, high energy yield, light high performance, etc.

KEYWORDS

Photovoltaic cells, Sliver cells, silicon, performances, IV curves

1. INTRODUCTION

The Sliver technology is the revolutionary crystalline solar cells technology which has been developed for manufacture of very thin and very efficiency photovoltaic cells. This new innovative technique was invented and developed at the Centre for Sustainable Energy System at the Australian Nation University in Canberra (the ANU) with financial support from Origin (Australian company involved in gas and oil exploration and production, power generation and energy retailing). The Sliver technology allows for large reduction in the usage of silicon compared to traditional silicon technology. The Sliver photovoltaic cells are produced on thin (c. 50 microns) and very wide (from 1 to 2 millimeters) silicon strips manufactured by the micromachining processes. This type of the solar cells producing should decrease silicon usage to 1 tone per MW of peak module in the foreseeable future (see Graph 1). On the top of this advantage the Silver technique has next qualities, e.g. excellent efficiencies, high open circuit voltage, bifacial illumination response or very good tolerance of reverse breakdown. Thanks these advantages Sliver modules might have become very perspective technology of solar cells manufacturing.



Graph 1 – Silicon usage for conventional and Sliver cells

2. WHAT IS SLIVER TECHNOLOGY?

2.1. Concept of Sliver photovoltaic cells

The Sliver solar cells are produces using 1 – 2 millimeters thick monocrystalline silicon wafers. The most important step in manufacturing is to form deep narrow grooves through these wafers (see Figure 1). For this occasion some varieties of technique can be used, e.g. scribing of laser, dicing saw or anisotropic etching processes. The alkaline etching process is the most widely used technique. 44wt % potassium hydroxide is used to etching that first are 10 micrometers openings in the etching mask. The wafers are moved in 5 minutes and out (next 5 minutes) of the solution the mechanical device.

The grooves typically have the pitch of 100 micrometers and the width of 40 micrometers which allows Sliver solar cells to have the thickness of 40 – 60 micrometers. Wafer about proportions 1.5 millimeters thick and 150 millimeters diameter would have about 1000 Sliver photovoltaic cells with a combined the surface area of c. 1500 sq. centimeters compared with the surface area of traditional photovoltaic cells manufactured using the wafer of c 177 sq. centimeters. The cells are removed from the wafer frame and they are laid on the sides (the groove sidewalls) after the process of the manufacture (see Figure 2). The results are symmetric, bifacial cells which are long, narrow and very thin. Fact is that Sliver cells have the width which is smaller than the thickness.

The edges of the cells are metallised to form the p and n-type contact (see Figure 3). Any of the contacts cover only c. 3% of the surface of the cells.

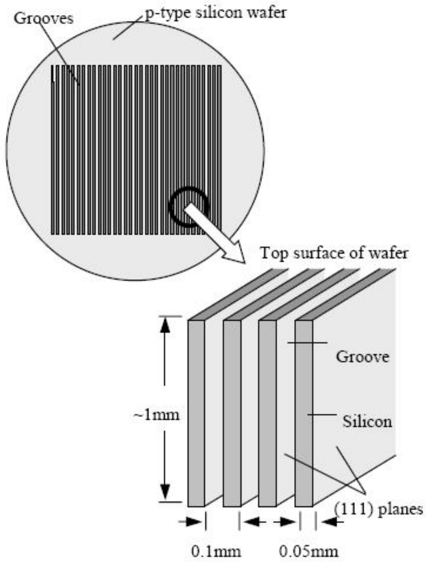


Figure 1 – Silicon wafer and Sliver cells

2.2. Innovative texturing technique

The sides of Sliver solar cells are textured using the new texturing method which has been invented at the Australian National University. The texturing is very important for all silicon photovoltaic cells to improve the light trapping. The texturing techniques which are used by traditional cells are not the most suitable for Sliver cells. That is why new texturing technique must have been developed.

The thin layer of material with the thickness variation is deposited onto the silicon. Then the isotropic etching over this layer implemented. The etching reaches bare silicon at the thinnest points in the layer and opens up round etch pits. The etching continues until the surface is covered with etch pits (see Figure 3). This texture offers near lambertian light trapping properties. The average path length in the silicon is better than factor of four. The textured Sliver cell thick 50 micrometers absorb more light than the untextured cells thick 200 micrometers. The reflection is reduced by the texturing either by direct reflection of light onto another surface of cells or by total reflection from the front cover glass after encapsulation.

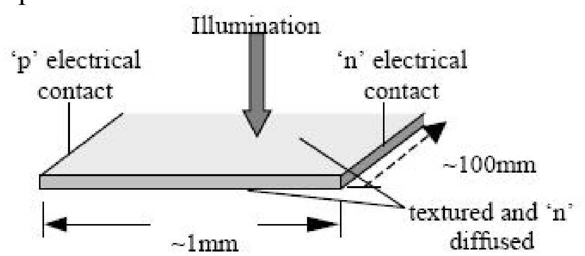


Figure 2 – Sliver cells cross section view

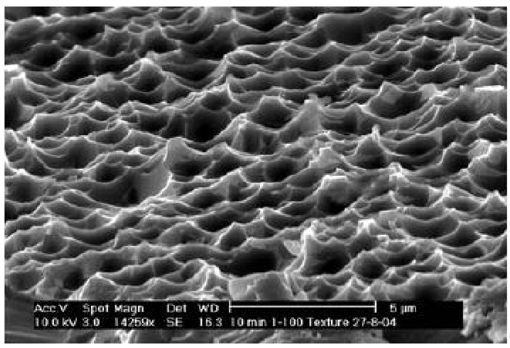
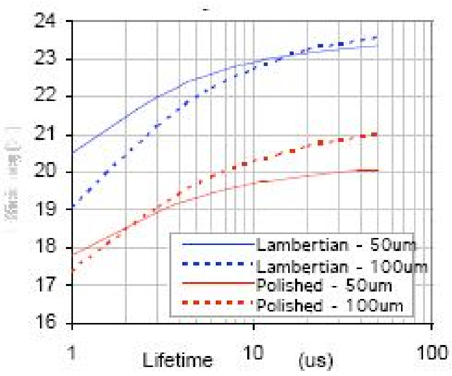


Figure 3 – Silicon surface covered with etch pits from texturing process

2.3. Most important optimum Sliver cells design

Bulk resistivity

One of the simplest design parameters which can be varied is the bulk resistivity of the starting wafers. The remainder of the process remains practically identical but the variation of bulk resistivity can greatly affect cell function. The cells are modelled for the range of the bulk resistivity values and over the range of the light intensities. The cells are fabricated from high purity wafers with good electronic lifetime. The clear relationships exist between bulk resistivity and minor carrier lifetime (see Graph 2) and between bulk resistivity and cell efficiency. The efficiency plateu exists for the range of low resistivities, efficiency dropping for both higher and lower resistivities. Maximum efficiency is for bulk resistivity of around 0.1 to 0.3 Ωcm. Higher bulk resistivity result in decrease of the efficiency. Lower bulk resistivity result in decrease short-circuit current and open-circuit voltage.



Graph 2 – Dependence of carrier lifetime on efficiency for Sliver cells with bulk resistivity of 0.1 Ωcm and thickness 50 and 100 micrometers

Resistivity (Ω.cm)	0.033	0.1	0.25	0.5	1	2.5	5	10
Lifetime (_s)	9	14	50	100	300	500	700	1000

Table 1 – Dependence of bulk resistivity on carrier lifetime

Cell thickness

The thickness of the Sliver cells is determined by the pitch of the micromachined grooves (it is mentioned above), by the minority carrier lifetime and by the length of the diffusion. The diffusion lenghts for 0.1 Ωcm float-zone silicon of greater than 100 micrometers are attainable. The cells which are produced from wafers of the higher resistivity have larger upper thickness limits.

2.4. IV curve of Sliver cells, fill factor

The IV curve of the Sliver photovoltaic cells is represented in Figure 4. This curve was measured in-house in air under nominally AM 1.5 g conditions by the cell about parameters: 77 millimetres long, 1 millimetre wide and 65 micrometers thick. The key cells characteristic is the open circuit voltage of 675 mV and short circuit current of 28 mA. The fill factor (FF) of this cell is c. 78%.

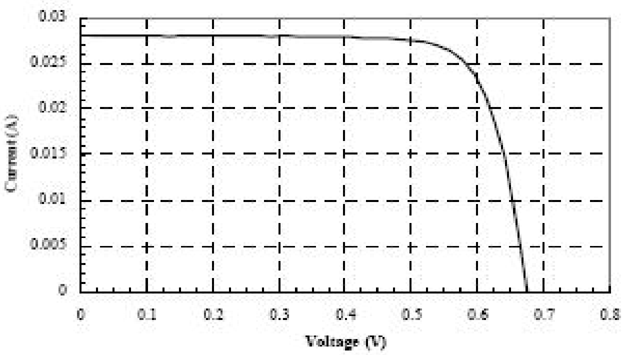


Figure 4 – IV curve of Sliver cell

2.5. Advantages of Sliver cells

The Sliver photovoltaic cells have many advantages. There are mentioned just few of them.

Reduction in the mass of the silicon belongs to the largest of them. In Table 2 there is the comparison of Sliver solar cells with traditional solar cells about thickness 320 micrometers and efficiency of 13.5 %. The silicon saving and process reduction comes through. Per one kW rating there is the reduction in the silicon usage of 8 – 12 times and reduction in the number of the necessary silicon wafer of 16 – 35 times.

Very short energy payback time is the second big advantage. It is estimated that this time will be only 1.5 years (more than two thirds of this time is thanks to the standard components, e.g. glass, encapsulate, etc).

Next advantages of the Sliver cells: Better quality silicon can be used to maintain higher efficiency due to the silicon saving. The possibilities obtain the high voltage in the very small cells to be used to the small power consumer products. The Sliver cells operate at the lightly lower temperatures than the traditional photovoltaic cell.

Wafer thick. (mm)	Gap size in module	Silicon savings kg/kW	Process reduction Wafer/kW	Model Effic. (%)
1.0	No gap	4 fold	10 fold	16.8
1.0	1x cell width	8 fold	16 fold	14.1
1.5	2x cell width	12 fold	35 fold	12.2

Table 2 – Comparison of Sliver cells and traditional solar cells

3. SLIVER MODULES

The Sliver module has been developed to further minimize the silicon usage by taking advantages of the Sliver cells.

The cells are positioned between the two glass layers or between the layers of other suitable materials. Some of the scattered light from the rear of the lambertian reflector is directed on the rear surface of the Sliver cell. Another part of the light is reflected onto the glass where it is totally internally reflected back in the Sliver module (see Figure 5). The light remainder is lost through the glass. This enables better usage of solar radiation thereby higher efficiency.

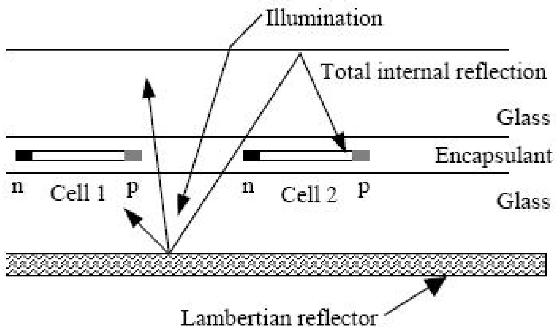


Figure 5 – Sliver module

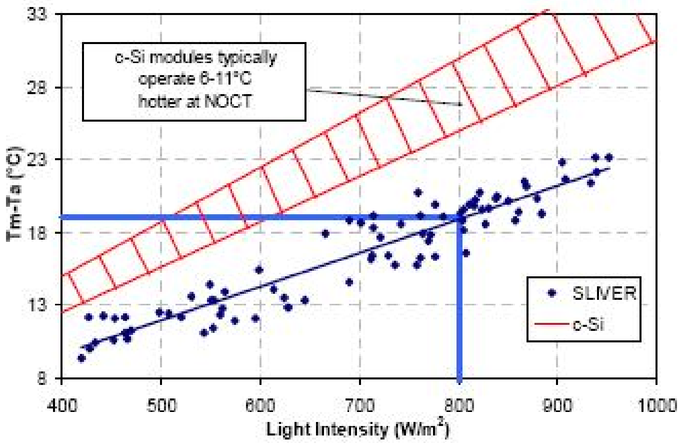
3.1. Most important performances of the Sliver modules

Each of the Sliver modules has a few of important performance, e.g. low operation temperature, low temperature coefficient, high energy yield, light high performance, etc.

Low operation temperature

Researchers of the ANU took measurement of the Sliver modules. For these measurements the Sliver modules with 76 W Pmax (maximum power) at the Standard Test Conditions (STC) were used. The average wind speed during the measurement was 1.1 m/s and the average ambient temperature was 21°C. These conditions are ideal for determining the module operation temperature at the Normal Operation Cells Temperature (NOCT).

The Sliver modules operate substantially cooler than traditional silicon modules. This is demonstrated in Graph 3 where it can be seen that Tm–Ta (relative to ambient temperature) responds linearly with light intensity. At 800 W/m^2 the module temperature is 19°C above ambient. The module temperature for the Sliver modules at NOCT is therefore 39°C. This compares extremely well to traditional solar cells which have NOCT in the range of 45 – 50°C.



Graph 3 – Effect of light intensity on module temperature

Low temperature coefficient

The Sliver cells have high open circuit voltage. The researches took the measurements of the temperature coefficents of Sliver photovoltaic modules with power 75 W. Values (absolute and relative units) are given in Table 3. E.g. temperature coefficient for Voc has value of -0.299 %/°C – this corresponds to -1.96 mV/°C per cell for these module. This coeffiecient for tradional solar cells has value of -0.36 %/°C. Sliver modules have temperature coefficient for Voc compared to convetional silicon module by approximately 20 % (in relative terms). This superior temperature coefficient was also confirmed for maximum energy where the value of -0.40 %/°C was measured.

Coefficient	Absolute Units	Relative Units
Voc (β)	-0.137V/°C	-0.299%/°C
Isc (α)	+1.7mA/°C	+0.079%/°C
Pmax (γ)	-0.31W/°C	-0.40%/°C

Table 3 – Measured temperature coefficients for 75 W Sliver module

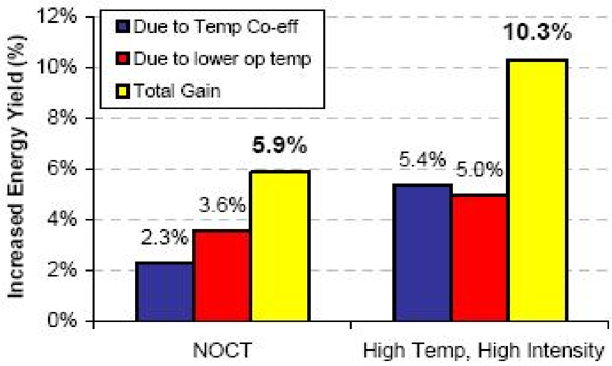
High energy yield

The lower operating temperature and the lower temperature coefficient provide the higher energy yield. The estimated of the higher energy field is practiced for the following typical conditions.

First condition: NOCT which has the ambient temperature of 20°C and the light intensity of 800 W/m^2. And second condition: the high temperature (of 40°C) and the high light intensity (of 1100 W/m^2). The estimated increases in energy yield for these two conditions are illustrated in Graph 4. It stands to reson that Sliver module generates (in estimation) 2.3 % more energy due to its superior temperature coefficient and further 3.6 % more energy due to its lower operating temperature. The total increase in the energy yield is estimated 5.9 % at NOCT compared to the traditional silicon photovoltaic cells.

The model for second conditions – the high temperature and the high light intensity – is silimilar. The energy yield of the Sliver modules is estimated to be even greater when the light intensity (or ambient temperature) is higher.

The Sliver modules generate (in estimation) 5.35 % more energy due to its temperature coefficient and further 4.95 % more energy due to its lower operating temperature. This is the total increase in energy yield od 10.3 %.



Graph 4 – Estimated increases in energy yield

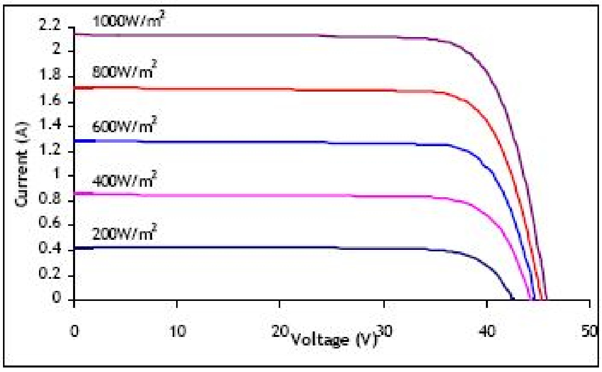
Low light performance

The Sliver cells have the high efficiency cell structure (it is noted above). The efficiencies in excess of 20 % have been achieved under laboratory conditions. The low light performance of the modules as therefore expected to be good with the little impact from non-ideal diode behaviour or shunt resistance.

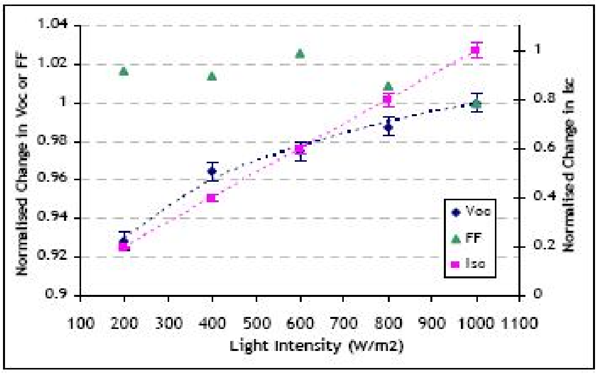
The measurements of 75 W Sliver module at different light intensities (and with STC conditions) is demonstrated in Graph 5. Voc of the Sliver modules decreases slightly with the light intensity as is expected for the silicon diode.

Graph 6 illustrates the dependency od Isc, Voc and FF with the light intensity for the IV curve which is in Figure 10. All values have been normalized against the values at STC, that means 2.14 A (Isc), 45.88 V (Voc), 77.8 % (FF) and 76.4 W (Pmax).

The dashed and dotted lines in Figure 10 are the theoretical curves fot the change in Isc and Voc. The curve for Isc is based on the purely linear response for Isc to the light intensity and the curve for Isc is based on the unavoidable Voc change expected from the ideal diode equation. The values of Isc, Voc and FF shows that the Sliver modules have the properties of the low series resistantce, very high shunt resistance and near unity ideality. This demostrates the good low light performance of these modules.



Graph 5 – IV curve for 75 W Sliver module at different light intensities



Graph 6 – Normalised change in Isc, Voc, FF

4. CONCLUSIONS

Problematic of the utilization of the photovoltaic cells will become more topical in the connection with the sharply increasing prices of the electrical power and thus new and superior technologies of their produce would have been developed. Sliver technology is one of the revolutionary photovoltaic cells technology which disposes of the high performances. This technology has the potential for dramatically reducing the cost of manufacture of the solar modules through silicon savings and reduced wafer requirements. Quite a few of the test of these cells have yet been carried out, e.g. the electrical performance test, the electrical isolation test, the wet insulation resistance test, the thermal cycle test, the UV conditioning test, etc. Other tests are planning to improve the actual performance.

We hope that the new technologies in the field of the photovoltaic systems will develop.

REFERENCES

[1] *Blakers, A.W.; Stocks, M.J.; Weber, K.J.; Everett, V.; Babaei, J.; Verlinden, P.J.; Kerr, M.J.; Stuckings, M.F.; Mackey, P.:* Sliver Solar Cells. Vail Colorado: August 2003.

[2] *Stocks, M.J.; Weber, K.J.; Blakers, A.W.; Babaei, J.; Everett, V.; Neuendorf, A.; Kerr, M.J.; Verlinden, P.J.*: 65-micron Thin Monocrystaline Silicon Solar Cell Technology Allowing 12-Fold Reduction in Silicon Usage. Osaka: May 2003.

[3] *Verlinden, P.J.; Blakers, A.W.; Babaei, J.; Everett, V.; Kerr, M.J.; Stuckings, M.F.; Gordeev, D.; Stocks, M.J.*: A New Thin Crystalinne Silicon Photovoltaic Technology. Bangkok: January 2004.

Author:

Ing. Hana Benešová
University of West Bohemia
Department of Electrical Power Engineering and Ecology
Univerzitní 8, 306 14 Plzeň, Czech Republic
E-mail: habe@kee.zcu.cz