SOLAR CELL SURFACE LOCAL REFLECTION AND PN JUNCTION AREA MEASUREMENT

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ABSTRACT

The objective of this paper is focused on study of solar cell parameters by advanced microscopy methods. Scanning Near-field Optical Microscopy (SNOM) is very useful modern tool for sample topography and surface reflectivity measurements. Using this, it is possible to determine *pn* junction area, localize some structure errors and investigate sample surface with submicron even subwavelength details. Accurate value of *pn* junction area is important parameter of solar cells, which is used for barrier capacitance calculations and improvement of solar cell effective value.

1. INTRODUCTION

Solar cells are ones of alternative energy sources, and so various types of solar cells are presently widely studied [1]. The worldwide research is focused on light to electric energy conversion efficiency improvement. Crystalline silicon is a dominant material for solar cell production over last 20 years. However, the multicrystalline silicon will be dominant in the future, nevertheless, a market for high-efficiency monocrystalline silicon solar cells will always exist [2]. The monocrystalline solar cells could be used in regions where the amount of solar radiation is low or in applications where space is limited.

For studying of monocrystalline silicon solar cell or its *pn* junction, it is necessary to know some parameters of sample. For example, a reverse biased measurement on semiconductors *pn* junction provides considerable information about its parameters and structural defects [3]. Some defects and parameters can be studied with using of advance microscopy methods [4].

Conventional optical microscopy resolution is limited by diffraction of light. This diffraction limit is known as the Rayleigh criterion and describes under what condition two objects are optically distinguishable [5]. Therefore a resolution of conventional optical microscopy could be increased by using shorter wavelengths. Other way is to circumvent the diffraction limit by using aperture smaller than the wavelength λ. The aperture scans over the sample point by point. Although advanced microscopy techniques such as atomic force microscopy (AFM), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and many others were developed, the proposed SNOM is useful tool for sample properties study. In contrast to other techniques, its resolution is lower, but it is possible to get some extra information such as local changes of refractive index, changes of refractivity, and changes of transmissivity or polarization [5]. Significant advantage of this microscopy type is that the topography can be taken as matrix of spatial values and it is possibility of the offline data processing.

2. SNOM FUNDAMENTALS

In general, SNOM is non-destructive non-contact measurement method. There are many microscope measurement configurations. Naturally, each configuration is suitable for slightly different purpose. Nevertheless, the basic principles are common for all known near-field optical microscope configurations.

2.1. TOPOGRAPHY MEASUREMENT PRINCIPLE OF OPERATION

The specially tapered optical fiber is used as the microscope scanning probe. This probe scans close to the sample surface in the near-near field in distances smaller than λ. From scanning tunnelling microscopy (STM) are known constant current mode (CCM) and constant high mode (CHM). In contrast to CCM, in CHM a probe is in constant high over the sample during whole measurement. So in CCM, a mechanism for probe feedback vertical movement is important. Mechanically this movement is provided by piezotube [6]. Possible feedback system of SNOM is shown on Fig 1.

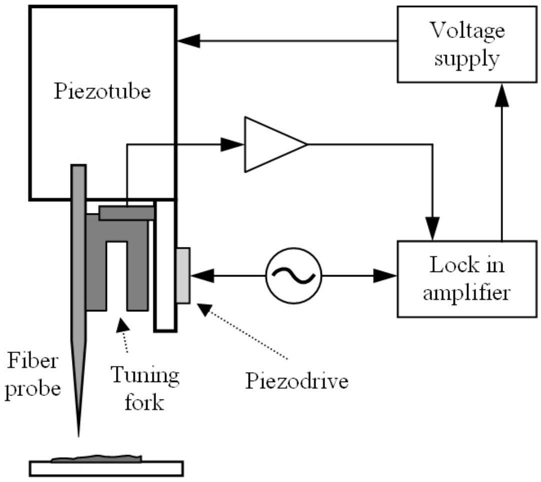

Fig. 1: SNOM feedback system

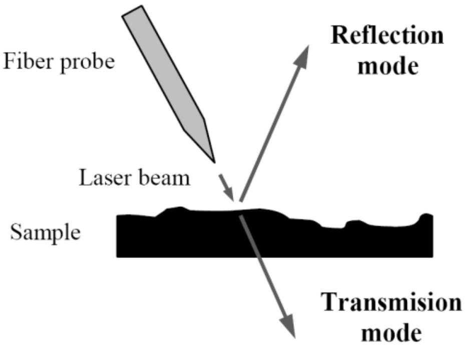

Fig. 2: Reflection and transmission mode

The fiber probe is glued onto the quartz tuning fork and is excited in transverse vibrations on resonance frequency by piezodrive. An electrical output of the quartz crystal has a voltage response due to the mechanical oscillation. If the tip is far away from the sample, it oscillates by free oscillation. During the approach to the sample surface, shear forces affect the tip oscillations. The distance between the tip and a surface can be influenced by value of the set-point which corresponds to required distance. The set-point is the oscillation amplitude after tip-sample approach. The information about fiber oscillation amplitude is then carried-out by the voltage response of tuning fork [7]. As a result, the probe scans over whole sample and creates topographic image of the latter.

2.2. MICROSCOPE REFLECTION/TRANSMISSION CONFIGURATION

The probe is made from sharpen optical fiber so it can transfer light. It is possible to use fiber tip as light collector, emitter or collector and emitter together. There are two basic modes: reflection mode and transmission mode. The difference between reflection mode and transmission one is shown in Fig. 2 (fiber tip is used as light emitter). Transmission mode could be used only if the sample is transparent, while the reflection mode is also suitable for opaque samples.

If the tip is used as the collector, the reflected light originates from a small sample surface area is collected. If the tip is used as emitter, the reflected light is collected by remote photomultiplier (PMT) in the far-field. Although the detection takes place in the far-field, reflected light comes from local area irradiated by the emitter. Figure 3 represents a reflection image of monocrystalline silicon solar cell sample with pyramidal texturing. This image could be taken simultaneously together with topography image. Therefore, this microscope configuration can be suitable for some structure defects observation and localization.

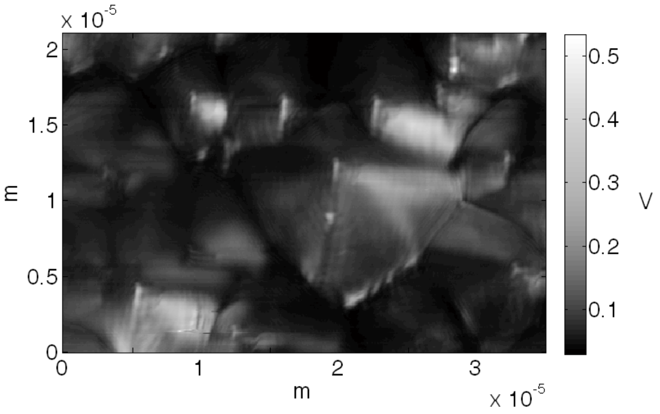

Fig. 3: PMT reflection of solar cell sample

3. SILICON SOLAR CELLS

Efficiency is one of the most important parameters of solar cells. Some structural errors and local mechanical damage of the cell result in lower efficiency. Reverse biased measurement on semiconductors *pn* junction provides considerable information about its parameters and defects. To calculate some parameters, such as barrier capacitance, it is necessary to recognize whole area of *pn* junction [3].

3.1. SOLAR CELL TEXTURING

Light to electric energy conversion efficiency can be improved by maximization of solar cell incident light absorption. Special pyramidal texturing (Fig. 4) upon solar cell surface could do this. When a light strikes on surface, the part of the light energy is reflected and part is absorbed or goes through. Due to pyramidal texturing, there is multiple reflection and greater light absorption. Texturing can be achieved by treating with an anisotropic chemical, which acts preferentially along the (111) crystal planes and leaves a pattern of pyramids on the surface [1].

From macroscopic point of view, the surface area S_1 of square solar cell is equal to second power of side size. Nevertheless, from microscopic point of view, the real surface area S_2 is larger due to the surface texturing. Providing the spatial distribution of wide *pn* junction is correlated with surface texturing due to diffusion technology of *pn* junction generation, it is possible to determine whole *pn* junction area.

3.2. PN JUNCTION AREA MEASURING

Using spatial integration of measured topography data, it is possible to get surface area. The easiest way to determine surface area is to sum triangles S_{A1}, S_{B1}, S_{A2}, ... areas as shown in Fig. 5. The measuring in various part of monocrystalline silicon solar cell sample confirms that the character of surface texturing is conformal. The measured sample has surface contacts and *pn* junction has pyramidal character also below contacts. From Figs. 4 and 5, the area increasing coefficient r = 1,64 expressing microscopic to macroscopic area ratio has been found. Using this coefficient it is then possible to calculate the *pn* junction area from macroscopic area.

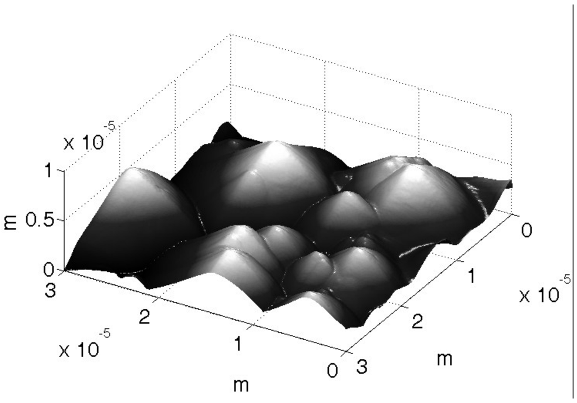

Fig. 4: Solar cell texturing SNOM topographic image, scanning velocity = 12,03 μm/s

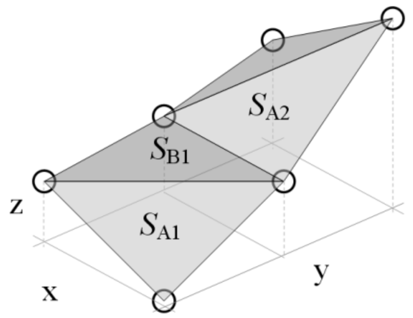

Fig. 5: Visualization of spatial surface area determination from SNOM measured topographic image

4. CONCLUSION

Although there are many microscopy techniques with higher spatial resolution, SNOM is useful tool for silicon solar cells measurement and defects localization. From measured topography data it is possible to evaluate the surface area by spatial integration. The result of *pn* junction area is obtained by multiplication of increasing coefficient r and macroscopically measured area of solar cell sample. Precise value of *pn* junction area is important parameter of solar cells and can be used for description of other properties of *pn* junction.

ACKNOWLEDGEMENTS

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