Investigation of ITO magnetron deposition effect on carrier lifetime degradation in silicon wafer

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Abstract. The effect of ITO magnetron deposition on carrier lifetime in silicon was demonstrated. The method of 2D photoluminescence decay time measurements revealed the lifetime degradation in silicon after magnetron deposition of thin ITO film which is used for top contact in modern solar cells.

1. Introduction
Modern solar cells are mainly produced from silicon due to its high availability and the developed Si technology. Silicon-based solar cell efficiency is determined principally by the quality of silicon wafer which acts as a volume where the carriers photogeneration and separation occurs. The record efficiency of 26.7% [1] was reached for the silicon solar cell produced from float-zone silicon. It’s a high-purity silicon wafer with extremely low concentration of defects. Photogenerated charge carriers in such wafer have high value of lifetime (more than several ms). High lifetime values promote the carriers to reach the silicon surface without significant recombination in the bulk. However the surface by itself consists of numerous abrupt bonds that act as a recombination centres. Nanosized passivation films (for example a-Si:H) on the both side of silicon wafer eliminate surface recombination resulting in more efficient current output. Hydrogen in such films saturates abrupt silicon bonds however the Si-H bond strength is quite low. Thermal heating, UV irradiation or plasma treatment can break off the Si-H bond and result in passivation degradation. Transparent conductive oxide (TCO) deposition is one of the stages for solar cells fabrication. Principally magnetron sputtering is used for the process. During the sputtering the sample (silicon covered by a-Si:H) is exposed to strong UV irradiation and to high kinetic particles collision. This could potentially destroy the passivation and moreover - create defects in the silicon surface layer. As a result the efficiency of the solar cell can be decreased. The aim of this work is to reveal the effect of indium tin oxide (ITO) magnetron deposition on the silicon passivation efficiency.

2. Experiment details
Cz as-cut n-Si(100) 1-7 Ohm-cm wafer with a thickness of 210 µm and a size of 40×40 mm² was used. Texturing and cleaning procedure was described earlier [2]. After an HF dip a 100 nm of a-Si:H layer was deposited on each silicon side by PECVD with Oxford Plasmalab equipment at a temperature of 250 °C. Then a two-dimensional (2D) photoluminescence (PL) decay measurements were carried out. Two-dimensions PL decay time measurements were performed on as-passivated by a-Si:H textured silicon wafer with the experimental setup shown in figure 1. The 850 nm IR laser was used to excite the sample during PL decay measurements. PL response from silicon was detected by low capacitance InGaAs photodiode (GAP500) with ultrafast amplifier from Analog Devices coupled with analog to digital converter managed by microcontroller and connected to PC. PL decay curves were measured...
with a fixed laser intensity of 70 mW/cm². Controllable moving of the measured sample allows to provide 2D measurements, i.e. to measure PL decay time locally on the whole wafer with a resolution of the order of 0.5 mm limited by laser spot and the photogenerated carriers diffusion length.

To investigate the effect of ITO sputtering on the front surface of the passivated silicon sample a 100 nm thick ITO layer was deposited by RF magnetron sputtering with BOC EDWARDS AUTO 500 RF Sputter. To separate the influence of different potential sources of degradation during the sputtering three different type of mask were used. Stainless steel mask with open areas of 4x4 cm² was used to form the separated ITO areas on the top sample surface. Mask from boron glass and fused silica were used to investigate the effect of strong UV irradiation during the first stages of TCO sputtering. The ITO deposition was carried out with a fixed magnetron power of 50 W and a chamber pressure of 10⁻³ mbar. Pure argon (99.999 %) was used as a working gas. The distance between magnetron source and the substrate was 8 cm. The deposition process duration was 10 min. As an ITO layer absorbs a part of incident light thus prior to the PL measurements the deposited film was selective etched in HCl:H₂O=1:3 solution.

3. Results and discussion

Figure 2 shows the result of 2D PL decay measurements for the 4x4 cm² textured silicon wafer passivated by a-Si:H.
In general an average PL decay value of about 200 µs is observed except the one region where the value is much bigger and reaches of 300 µs. Probably it is related to the inhomogeneities in silicon wafer attributed to the different impurities distributions.

Figure 3a shows a mask placement on the passivated silicon substrate and the result of ITO magnetron deposition (Fig. 3b). Dark areas are the ITO thin layers deposited on silicon and due to refractive index of 2.0 the transparent conductive layer acts as a single layer antireflective coating leading to optical reflection decreasing.

![Figure 3a](image1.jpg)  ![Figure 3b](image2.jpg)

**Figure 3.** Photo of a mask placement on a-Si:H passivated silicon wafer (a) and the result of the ITO deposition (b).

Next, the deposited ITO layer was selective etched in HCl:H₂O=1:3 solution to eliminate its influence on PL decay measurements. After the etching visible patterns from the metallic mask in the top part appeared (Fig 4a). This points out on some degradation of a-Si:H thin layer. The corresponded 2D PL decay measurements are shown in figure 4b.

![Figure 4a](image3.jpg)  ![Figure 4b](image4.jpg)

**Figure 4.** Photo of a top a-Si:H passivated silicon surface after ITO etching (a) and the corresponding PL decay mapping (b) of the sample.

It can be seeing that after ITO deposition and dissolving the maximum value of the PL decay time was decreased from 325 to 260 µs. As the initial PL decay distribution was not homogeneous there was a precise calculation realized to show the difference between the initial PL map and the final (Fig. 5). It is clearly visible that at the areas where the ITO film was deposited and then etched a strong PL decay
time decreasing is observing. The highest degradation is observed at the top areas where were seen the visible patterns form metallic mask (Fig. 4a).

![PL decay mapping difference between the measured on the a-Si:H passivated silicon and after the ITO deposition/etching](image)

**Figure 5.** PL decay mapping difference between the measured on the a-Si:H passivated silicon and after the ITO deposition/etching

Metallic mask was placed at top and the bottom parts of the sample but the degree of passivation degradation is different. Taking into account the visible patterns on the top part of the sample after the ITO etching it can be assumed that the ITO deposition conditions during magnetron sputtering are vary by the Y coordinate. The distance between magnetron source and the substrate was 8 cm. The sample size was 4×4 cm². For such low distance and considering the size of the sample there is a probability that at outer areas the sputtered particles (In, O and Sn) will have different local concentration and kinetic energy. Figure 6 shows measured values of sheet resistance (Rₛ) for 100 nm ITO film deposited on glass substrate in regimes similar to this work.

![ITO sheet resistance as a function of the sample placement on the sample holder for two different magnetron source to sample distances](image)

**Figure 6.** ITO sheet resistance as a function of the sample placement on the sample holder for two different magnetron source to sample distances.

Sheet resistance in ITO film is defined by the concentration of the three elements and the defects formed during the deposition. The investigated sample was located inside the region between 2 and 6
cm where the $R_s$ value is minimal. The most degraded area on a-Si:H passivated silicon sample was located at a distance of 6 cm from the sample holder edge. According to figure 6 at this area $R_s$ is starting to increase but is still low. So the reason for such high degradation of PL decay in the top region is still unclear. As an assumption it could be an excess of oxygen particles which reacts with hydrogen from a-Si:H layer leading to the passivation degradation that visually appears due to refractive index change [3].

As it shown in figure 5 areas masked by boron glass or fused silica didn’t show any distinct degradation of PL decay time after ITO magnetron deposition. Thus can be concluded that strong UV radiation during ITO deposition didn’t affect on passivating properties of 100 nm a-Si:H layer. And the described earlier effect of passivation degradation is related only to chemical or kinetical interactions between sputtered ITO and a-Si:H layer.

Acknowledgments
This work was supported by the Russian Scientific Foundation under grant number 18-79-10059.

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