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# Study of Short-Circuits in Multicrystalline Si based Cells by the LBIC, EL and EDS Methods

[1]Valery I. Orlov, [2]Evgeniy B. Yakimov, [3]Eldar P. Magomdbekov and [4]Alexey B. Danilin
[1]Institute of Solid State Physycs RAS, Chernogolovka, Russia
[2]Institute of Micrielectronocs Technology RAS, Chernogolovka, Russia
[3]D. Mendeleev University of Chemical Technology of Russia, Moscow, Russia
[4]Limited Liability Company "Innotra", Moscow, Russia

**Abstract:** When using Si solar cells, there can be some difficulties due to shunts which lead to short circuits that can cause a malfunction and the melting of the electrical wires with possible inflammation. Breakdown sites in multicrystalline Si solar cells have been studied by the reverse-bias electroluminescence by the electron (EBIC) and Laser Beam Induced Current (LBIC) and energy dispersive X-ray spectroscopy methods. In the breakdown sites revealed by EL at small reverse bias (~5 V) the enhanced aluminum and oxygen concentration is revealed. Such breakdowns can be located inside the depletion region because they are not revealed by the EBIC or LBIC methods. Breakdowns revealed by EL at larger bias well correlate with extended defects in the EBIC and LBIC images.

**Key words:** Reverse bias electroluminescence, EBIC, LBIC, solar cell, breakdown, malfunction

## INTRODUCTION

Solar cells made from Si regularly suffer from shunts which are internal short circuits degrading the parameters of the cells and often even preventing their applicability (Breitenstein *et al*., 2004; Dongaonkar *et al*., 2010; Großer *et al*., 2012). Therefore, it is very important to study their nature and to understand the mechanisms of their formation. The danger is that if a short circuit is sharply and repeatedly increases the amount of current flowing in the circuit that according to the law of Joul-Lenz leads to a significant dissipation and as a consequence, it is possible to melting of electric wires, followed by the appearance of fire (Bulat and Volkov, 2016). In spite of numerous studies done by various researcher the cause and occurrence of shunts in solar cells are not fully understood yet. It is determined by a manifold nature of shunts, especially in multicrystalline Si and by a variety of extended defects and impurities in this material. Among various types of shunts those associated with local breakdown of solar cells under reverse bias can be mentioned (Breitenstein *et al*., 2010; Schneemann *et al*., 2015). Such shunts can be revealed by the reverse-biased Electro Luminescence (EL) (Sugimura *et al*., 2012) and the correlation the EL images with those obtained by the Electron Beam Induced Current (EBIC) method sometimes allows to find a link between these shunts and extended defects. However, for some shunts no any correlation with extended defects was revealed.

In the present, study the shunts in multicrystalline Si based solar cells are revealed by the reverse-biased EL. The EL images obtained at different reverse bias values are compared with those obtained by EBIC and Laser Beam Induced Current (LBIC) methods to correlate them with extended defects. A local composition at the breakdown sites was studied.

## MATERIALS AND METHODS

Solar cells studied were formed on the multicrystalline Si wafers cut from bricks grown by casting. The surface is textured with structures of several micrometers depth in order to maximize light capture. The electroluminescence images were recorded using an optical microscope and a high-sensitive video camera equipped with a silicon charge-coupled device array. The EBIC investigations were carried out in a Scanning Electron Microscope (SEM) JSM 840A (Jeol) at room temperature with beam energy of 35 keV and beam current of $10^{-10}$A. The LBIC measurements were carried out at room temperature with a 980 nm semiconductor laser as an excitation source. Solar cell breakdown is often associated with precipitates. To study the nature of these precipitates the local composition in the breakdown sites was determined by the Energy Dispersive x-ray Spectroscopy (EDS) in the JSM 6490 (Jeol) with INCA 350 system (Oxford instrument).

**Corresponding Author:** Eldar P. Magomdbekov, D. Mendeleev University of Chemical Technology of Russia, Moscow, Russia

## RESULTS AND DISCUSSION

Large area EL image of solar cell obtained at reverse bias of 10 V is shown in Fig. 1. A lot of inhomogeneously distributed breakdown defects of different form can be seen as bright points. The images of cell fragment obtained at different reverse bias values with the higher magnification are shown in Fig. 2. It is seen that at small bias only a few breakdown sites can be revealed as bright spots while a number of these bright points increases with applied bias.

Typical breakdown sites revealed at EBIC and LBIC images of the same region (Fig. 3) does not reveal any electrically active extended defects in these sites. Therefore, it could be assumed that the corresponding defects are located in the depletion region or in highly doped $n^+$-layer where they do not produce the EBIC or LBIC contrast. In the secondary electron image surface stains were revealed at some breakdown sites (Fig. 4 and 5) but at other sites no surfaces defects were revealed at the positions of type 1 breakdowns. EDS mapping reveals the enhanced aluminum and oxygen concentrations at these sites that well correlates with the results obtained by Lausch *et al*. (2010) where it was concluded that these breakdowns arise due to contamination of the wafer with aluminium particles before and during processing. It should be noted that as shown by Heinz *et al*. (2014), Al spikes can indeed produce short-circuits in solar cells (Kwapil *et al*., 2009) (Fig. 6). I can come from Ag paste used for a top contact formation in which Al sometimes is added, although the breakdown sites studied are located far enough from the contact grid. It should be mentioned that at the right breakdown site presented in Fig. 2b the composition is more complex.

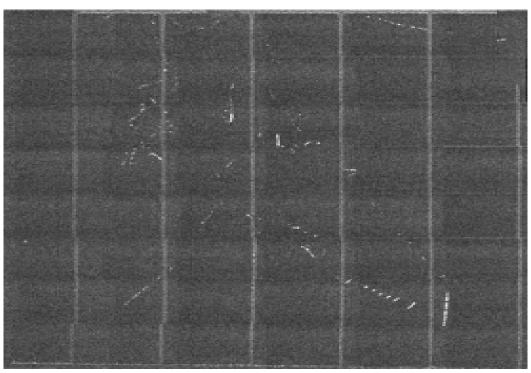

Fig. 1: EL image of large area fragment of structure under study. The distance between contact strips is 2.28 mm

Besides, aluminum and a small amount of oxygen the enhanced concentration of carbon and sodium is also revealed. As assumed by Breitenstein *et al.* (2010) and Moller *et al.* (2010) SiC filaments can be a reason for some shunts. Therefore, for these particular shunts 2 possible reasons for breakdown could be considered.

**Al spikes may be also formed on the SiC filaments:** In order to determine the spectral distribution of the luminescence arising from the type 1 breakdowns spectrally resolved EL measurements were performed at different reverse voltages for a few of them. Typical EL spectra obtained from the breakdowns of type I are presented in Fig. 7. It is seen that the spectra are practically independent of applied reverse bias. They exhibit a broad band ranging from 400 nm beyond 750 nm.

Those observed by Lausch *et al.* (2010) however, they have a maximum at about 570 nm, i.e., they are blue shifted according to 715 nm observed in boundaries introduce breakdown sites (Lausch *et al*., 2010).

Therefore, the assumption that the precipitates formed on grain boundaries and other extended defects are the reason. An analysis of EBIC and LBIC images of the same region shows that bright sports revealed at larger reverse voltage correlate well with some grain boundaries (compare Fig. 2c and 3). This is in a good agreement with the previously observed results for breakdowns of Type 2. Thus, such shunts can be associated with the specific grain boundaries or with

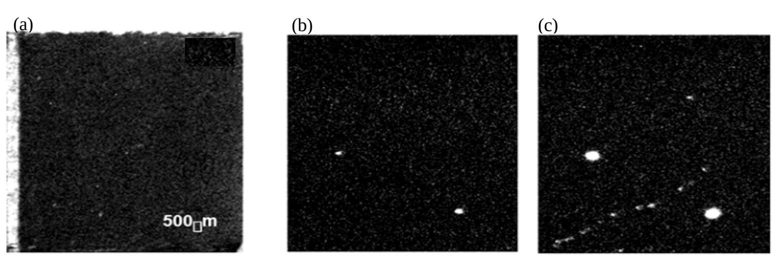


Fig. 2: EL images of solar cell fragment obtained at reverse bias: a) $U_b$= 0; b) 5 and c) 19 V

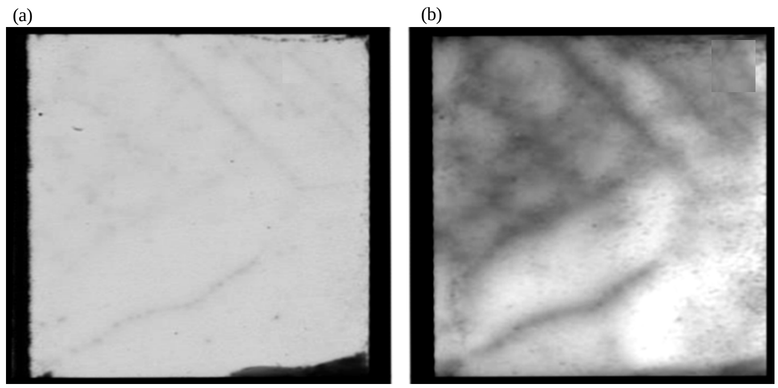


Fig. 3: a) EBIC and b) LBIC images of the same region as in Fig. 2

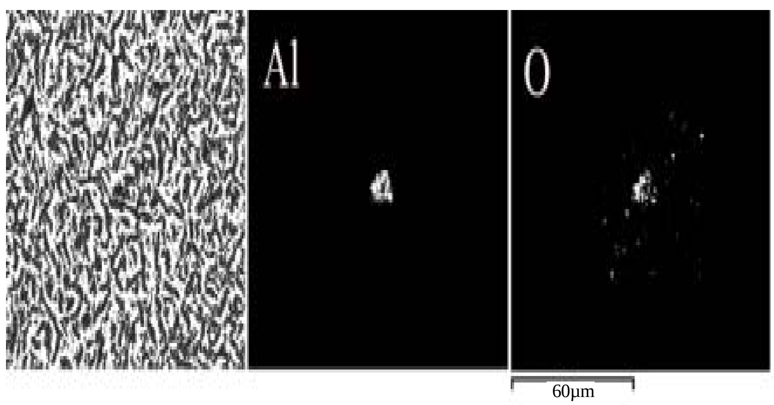


Fig. 4: SE image and EDS maps of aluminum and oxygen distribution for the left breakdown site in Fig. 2b

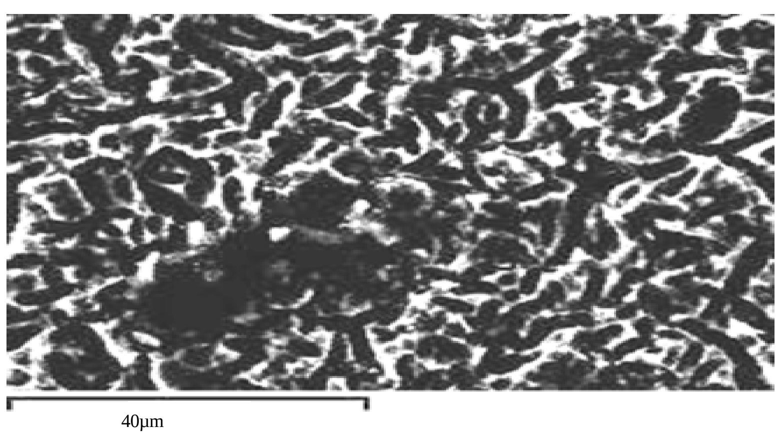


Fig. 5: SE image of right breakdown site in Fig. 2b, these spectra are similar to 2b

precipitates on these boundaries. As seen in Fig. 2c the EL images of such breakdowns are not continuous lines but instead consist of bright point sets. Moreover, not all electrically active grain for breakdowns of type 2 seems to be more reasonable. It should be noted that in the EBIC image of grain boundary producing the breakdown sites (Fig. 3a) some dark points can be also seen. That is precipitates decorating this grain boundary can be revealed in the EBIC mode. Our EDS investigations do not reveal any compositional changes in such breakdown

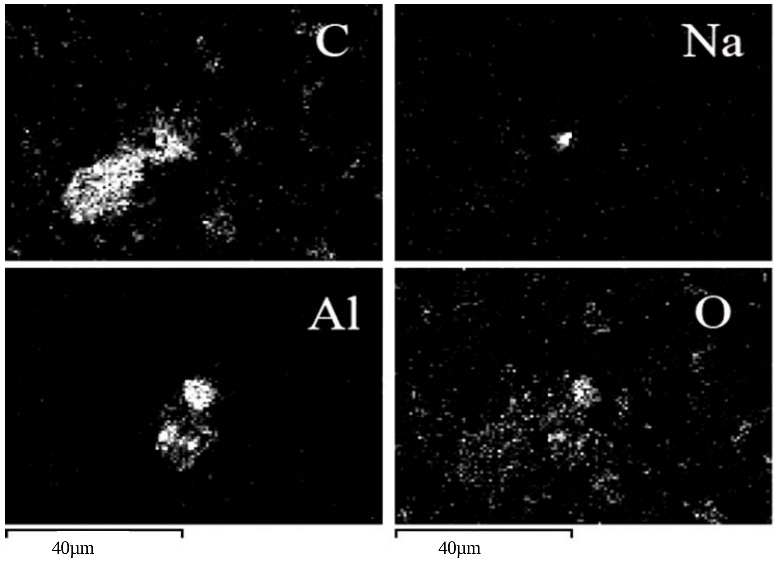


Fig. 6: EDS maps for the right breakdown site in Fig. 6 spectra are similar to 2b

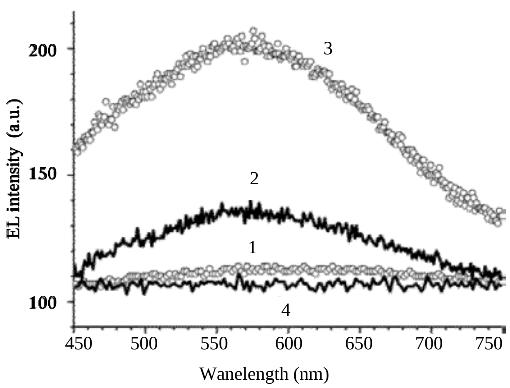


Fig. 7: EL spectra of breakdowns measured at reverse bias of 5 (1), 6 (2) and 9 V (3). The spectrum of breakdown free region measure at 9 V is also shown (4)

sites however, it should be taken into account that the sensitivity of EDS method in the scanning electron microscope due to rather large excitation volume is rather low and this method cannot detect small precipitate.

## CONCLUSION

Breakdown sites in multicrystalline Si solar cells have been studied by the reverse bias electroluminescence, EBIC, LBIC and EDS methods. The breakdown sites revealed by EL at small reverse bias could be associated with Al spikes located inside the depletion region. Breakdowns revealed by EL at larger bias well correlate with extended defects in the EBIC and LBIC images and can be associated with small precipitates formed at extended defects.

## ACKNOWLEDGEMENT

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