Carrier-selective junctions based on junctions between polycrystalline and monocrystalline silicon – a key building block for ultrahigh efficient Si solar cells

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Motivation

The importance of high energy conversion efficiencies of solar cells is recently increasing due to the need to counterbalance the increasing fraction of the balance of system (installation, inverter, cables, mounting,…) costs [1]. In order to minimize the recombination losses in a solar cell, in particular those occurring at the metal-semiconductor interfaces in the contacted regions, "carrier selective junctions" (CSJ) are desirable. CSJ are transparent for one carrier type while blocking the other carrier type, i.e., preventing the minority carriers to reach the highly recombination-active metal-semiconductor interface. A promising CSJ candidate are junctions between polycrystalline (poly-) Si and monocrystalline (c-) Si, which are known from bipolar microelectronics [2].

In the framework of the *SIMPLIHIGH* project, which is funded by the German Federal Ministry for Economic Affairs and Energy under Grant 0325478, ISFH and MBE are cooperating in order to transfer the poly-Si/c-Si technology from bipolar microelectronics to photovoltaics. From the LNQE facilities, multiple tools are utilized in this project: the poly-Si layers are deposited by Low-Pressure Chemical Vapor Deposition (LP-CVD) in a tool from centrotherm, doping of the poly-Si layers is mainly performed by ion implantation using an ion implanter from Varian, and structural investigations of the poly-Si/c-Si interface are performed utilizing a Transmission Electron Microscope (TEM) from FEI.

Results

Despite of the numerous investigations of poly-Si/c-Si junctions performed in bipolar microelectronics, the current transport mechanism across these types of junctions is still not fully understood. Existing models assuming a tunneling of charge carriers through an interfacial oxide between the poly-Si and the c-Si fail to describe consistently the behavior of junctions with n-doped and p-doped poly-Si. Therefore, we have developed an alternative, rather simple analytical model assuming a dominant current flow through pinholes in the interfacial oxide [3] (Fig. 1). This model does reproduce experimentally observed recombination current densities and junction resistances for both configurations – n and p-doped poly-Si.

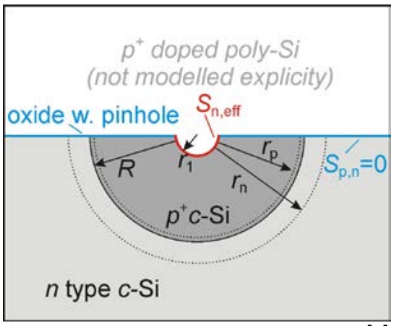

Figure 1: Illustration of an analytical model [3] describing the current flow in poly-Si/c-Si junction

Experimentally, we have developed a fabrication process for poly-Si/c-Si junction with excellent passivation quality for both polarities – n-doped and p-doped poly-Si. The recombination current densities at these junction are only 1fA/cm^2 for n-doped poly-Si and 4.5fA/cm^2 for p-doped poly-Si [4]. The fabrication process is based on LP-CVD deposition of intrinsic poly-Si on a ~2nm thin interfacial oxide, followed by ion implantation for doping (Fig. 2a). On symmetrical test structures (Fig. 2a), we have demonstrated that the passivation quality of the poly-Si/-Si junctions is that

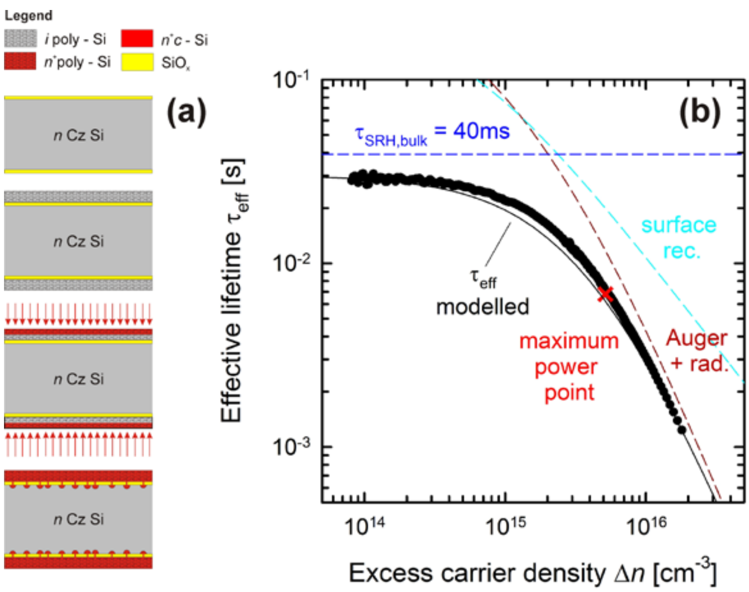

Figure 2: (a) Fabrication process of poly-Si/c-Si junctions, (b) Effective lifetime vs. excess carrier density, measured by the photo conductance decay method. The cyan line represents the limitation induced by recombination at the poly-Si/c-Si junctions.

excellent that it does not limit the effective minority carrier lifetimes any more (Fig. 2b). Rather, the effective lifetimes are limited by recombination in the Si wafer itself (either Shockley-Read-Hall or Auger recombination).

Outlook

Eventually, ion implantation can be patterned in-situ by introducing shadow masks into the ion beam. This enables a very lean and therefore potentially cost-effective process for the fabrication of back-junction back-contacted solar cells which require patterned doped regions on the rear-side (Fig. 3). Since this solar cell structure does not suffer from optical shading induced by front-side metallization, it has the potential for a high short-circuit current. Combined with the high open-circuit voltage and fill factor potential enabled by the poly-Si/c-Si CSJ, efficiencies above 25% are feasible.

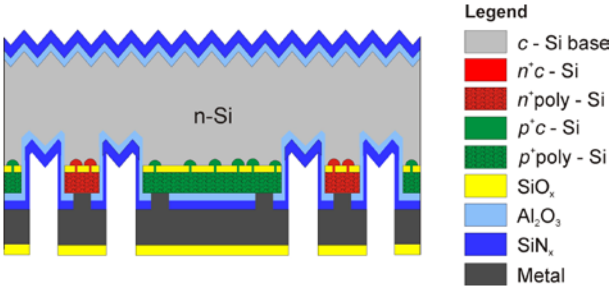

Figure 3: Back-junction back contacted Si solar cell structure with carrier selective poly-Si/c-Si junctions.

References

[1] International Technology Roadmap for Photovoltaic (ITRPV), 2013 edition, www.itrpv.net

[2] I. R. C. Post, P. Ashbum, and G. R. Wolstenholme, IEEE Trans. Electron. Devices, vol. 39, no. 7, pp. 1717–1739, (1992).

[3] R. Peibst, U. Römer, K. R. Hofmann, B. Lim, T. F. Wietler, J. Krügener, N.-P. Harder, and R. Brendel, IEEE Journal of Photovoltaics 4 (3), pp.841-850(2014).

[4] U. Römer, R. Peibst, T. Ohrdes, B. Lim, J. Krügener, and Rolf Brendel, submitted to IEEE Journal of Photovoltaics (2014).