Openbaar eindrapport TKI Urban Energy project COMPASS

April 30, 2018

Targets of the project and project partners

The 26.7% world record c-Si solar cell by Kaneka is based on amorphous silicon passivating contact technology. However, base materials alternative to amorphous silicon exist for passivating contacts, which not only have attractive passivating and conductive properties, but also have other technological or industrial advantages, such as higher transparency or better thermal stability.

In order to maintain a competitive edge in Dutch solar cell knowhow and equipment manufacturing, the goal of the COMPASS project was to explore, combine, and demonstrate high-performance and manufacturability of such novel, high-potential passivating contact materials, developed in the Netherlands. Novel passivating contact stacks and conductive layers developed by ECN, TU/e, TUD, AMOLF, and Solmates were tested by replacing parts of well-controlled device structures, such as silicon heterojunction (SHJ) solar cells, with these layers. In parallel, at Solmates, Levitech and ECN, implementation of the novel layer deposition processes was tested in their industrial tools and a first optimization was performed to estimate the industrial applicability. In the meantime, ECN and TUD have worked on the best design for a high-efficiency solar cell with two passivating contacts.

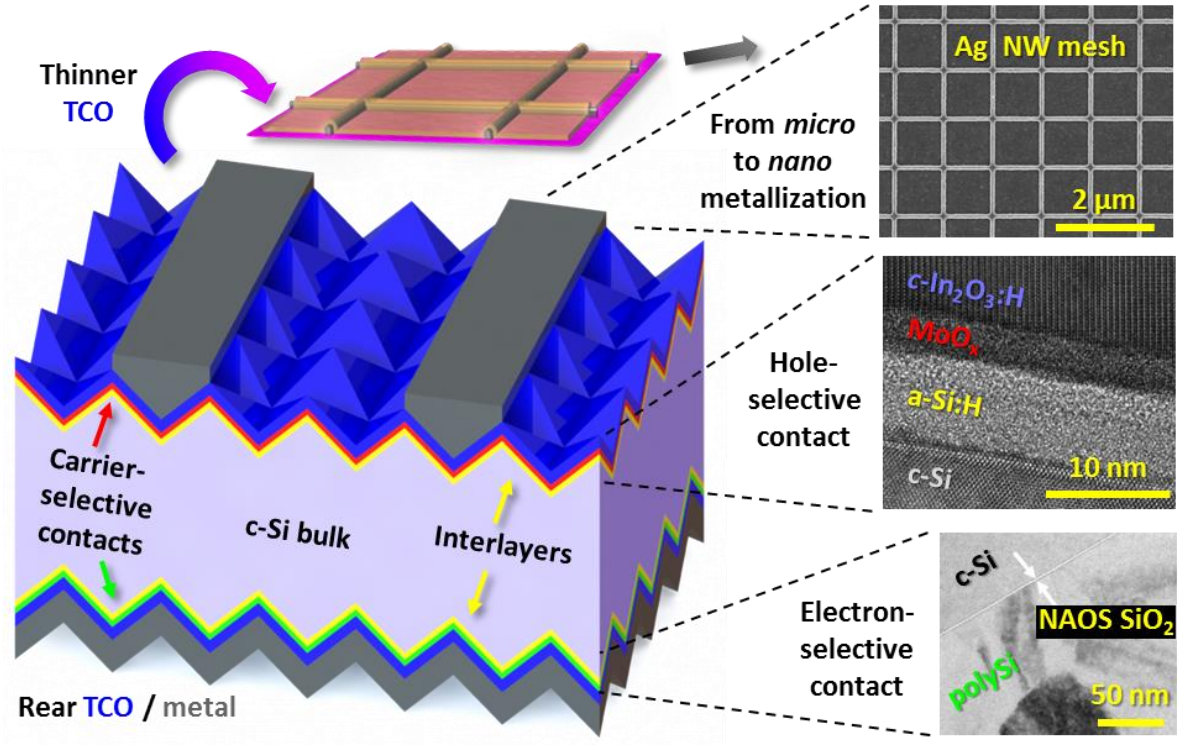
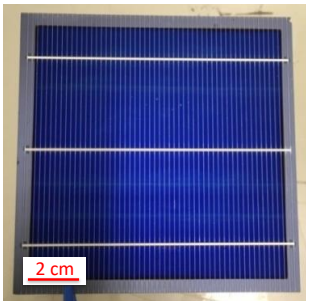


Figure 1. Sketch of a 'moly-poly' cell, the device developed in the COMPASS project. It has both contact polarities formed by novel passivating contacts. On the front side the passivating contact has MoO_x as the hole-selective layer, covered by a thin layer of In_2O_3:H or PLD ITO and a Ag NW mesh for lateral conductivity. On the rear side there is a SiO_2/n-type polysilicon stack covered with (optional) TCO and a full area metal contact.

Project result

In the COMPASS project a process for manufacturing a 6 inch moly-poly solar cell was developed. This is a solar cell with at the front side a contact based on a metal oxide, i.e.

molybdenum oxide (MoO_x), and at the rear side an n-type doped poly-Si based contact, which combines the strengths of the different partners. At the end of the project, the contributions of the different partners were combined in an integration run on cells with passivating contacts on both sides. The result of this integration run was **a new world record** for this moly-poly cell concept, with a much larger cell area than the previous record for this solar cell structure. This is a very promising result that has motivated all partners to continue with the development of this type of double-passivating contact solar cells on industrial scale.



J_{sc} (mA/cm^2)	35.9
Voc (mV)	686
FF (%)	73.0
pFF (%)	82.4
Eta (%)	18.1

Figure 2. Picture and JV parameters of the world record moly-poly solar cell. The metal grid was not ideally matched to the sputtering mask, which negatively impacted J_{SC} and FF.

Potential for application and spin-off

Wafer-based crystalline silicon PV technology is the dominant technology having a market share of about 90%, of which so-called p-type multicrystalline silicon PV is the main one. However, n-type silicon PV has the potential for higher efficiencies due to its lower sensitivity to most common transition metal impurities and the absence of light-induced degradation. The high-end quality PV modules of Sunpower and Panasonic are based on n-type monocrystalline material. Because of the growing market, better economic opportunities, demand for higher efficiencies, etc. the market situation will further improve and create openings for installing novel technologies like the moly-poly cells developed in this project. The whole market, from manufacturers to PV installing companies, from equipment vendors to engineering companies, and finally the end-user (consumers) will profit because of improved margins and lower LCoE. Dutch equipment suppliers will benefit even more, because of their better knowledge position.

Contribution to targets of TKI Urban Energy

The targets of the TKI Urban Energy are a sustainable infrastructure and a reinforcement of the knowledge position. The COMPASS project has contributed towards reaching this goal through the generation of Dutch knowledge that will lower the production costs of highly efficient solar cells and rigorously simplify the solar cell production process. This lowers the price of solar energy. Furthermore, in the context of the COMPASS project, solutions have been found based on equipment that is being developed in the Netherlands, which reinforces both the knowledge position and the Dutch economy.

Publications related to the COMPASS project

1. B. Macco, H.C.M. Knoops, M.A. Verheijen, W. Beyer, M. Creatore, W.M.M. Kessels, *Atomic layer deposition of high-mobility hydrogen doped zinc oxide*, Solar Energy Materials and Solar Cells vol. 173, 2017, pp. 111–119.

2. J. Melskens, B.W.H. van de Loo, B. Macco, L.E. Black, S. Smit, W.M.M. Kessels, *Passivating Contacts for Crystalline Silicon Solar Cells: From Concepts and Materials to Prospects*, IEEE Journal of Photovoltaics vol. 8, 2018, pp. 373–388.

3. M.W. Knight, J. van de Groep, P.C.P. Bronsveld, W.C. Sinke, Albert Polman, *Soft imprinted Ag nanowire hybrid electrodes on silicon heterojunction*, Nano Energy vol. 30, 2016, pp. 398–406.

4. Y. Kuang, B. Macco, B. Karasula, C.K. Ande, P.C.P. Bronsveld, M.A. Verheijen, Y. Wu, W.M.M. Kessels, R.E.I. Schropp, *Towards the implementation of atomic layer deposited In_2O_3:H in silicon heterojunction solar cells,* Solar Energy Materials and Solar Cells vol. 163, 2017, pp. 43–50.

5. P. Spinelli, M. Ah Sen, E.G. Hoek, B.W.J. Kikkert, G. Yang, O. Isabella, A.W. Weeber, P.C.P. Bronsveld, *Moly-Poly Solar Cell: Industrial Application of Metal-Oxide Passivating Contacts with a Starting Efficiency of 18.1%*, oral at Silicon PV conference, Lausanne, Switzerland, 19-21 March 2018, proceedings in Energy Procedia.

6. M. Ah Sen, P. Spinelli B. Kikkert, E. Hoek, B. Macco, A.W. Weeber, P.C.P. Bronsveld, *Electron Beam Evaporated Molybdenum Oxide as Hole-Selective Contact in 6 Inch c-Si Solar Cells,* poster at Silicon PV conference, Lausanne, Switzerland, 19-21 March 2018, proceedings in Energy Procedia.

7. J. Melskens, W.J.H. Berghuis, R.W.H.S. Scheerder, B.W.H. van de Loo, B. Macco, L.E. Black, W.M.M. Kessels, *Tailoring Atomic-Layer-Deposited TiO_x to Form an Electron-Selective Passivating Contact*, oral Silicon PV conference, Lausanne, Switzerland, 19-21 March 2018.

8. G. Yang, P. Guo, P. P. Moya, A. Weeber, O. Isabella, M. Zeman, *Poly-crystalline silicon-oxide films as carrier-selective passivating contacts for c-Si solar cells*, Applied Physics Letter, April 2018 (accepted).

9. L.E. Black, B.W.H. van de Loo, B. Macco, J. Melskens, W.J.H. Berghuis, W.M.M. Kessels, *Explorative studies of novel silicon surface passivation materials: considerations and lessons learned* (invited, paper under review), Solar Energy Materials and Solar Cells 2018.

10. G. Yang, P. Guo, P. P. Moya, G. Limodio, A. Weeber, O. Isabella, M. Zeman , *High efficiency c-Si solar cells with poly-silicon and poly-silicon oxide as carrier-selective passivating contacts* (invited, paper under review), Solar Energy Materials and Solar Cells 2018.

11. B. Macco, B.W.H. van de Loo, J. Melskens, P.C.P. Bronsveld, P. Spinelli, W.M.M. Kessels, *Effective surface passivation of c-Si by atomic layer deposited MoO_x layers for hole-selective contacts*, EU-PVSEC 2017, poster presentation.

12. B. Macco, B.W.H. van de Loo, H.C.M. Knoops, J. Melskens, W.M.M. Kessels, *Atomic hydrogen: Enabling Highly Transparent, Conductive and Passivating Metal Oxides for c-Si Photovoltaics*, MRS Fall 2017, oral presentation.

13. B. Macco, J. Melskens, B.W.H. van de Loo, L.E. Black, W.J.H. Berghuis, W.M.M. Kessels, *xSi PV Technologies: Status and Outlook of Passivated Contacts and Rear Contacted Solar Cells*, TKI days plenary meeting, June 2017.

Contact persons for more information

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