Jef Poortmans,
Program Director photovoltaics

Imec makes world record solar cells by using SoLayTecs' ALD

"In our semiconductor affiliation program at imec we have been using ALD for many years", Program Director PV Jef Poortmans states . "Especially, when a certain layer needs to be very dense, uniform, conformal and to be deposited at high speed, the spatial ALD technique is a unique option."

From the beginning the PV affiliation program at imec has focussed on developing high efficiency cell concepts. Jef Poortmans continues: "Since the start of our program we knew that ALD was needed just like in the semiconductor industry. In that period we reviewed several ALD methods and the SoLayTec principle got our strong attention. Because we directly understood the potential of real ultrafast ALD concept with the spatial ALD principle." In the first phase this potential was shown by TNO employees in collaboration with one of my Ph.D students, Bart Vermang, in a rotating setup (see figure 1) that clearly proved the feasibility of deposition rate of 1nm/second, which is for ALD extremely fast. In this setup the wafer was rotated underneath an injector head. This head has two different precursors, a water vapour and a TMA vapour, that creates the Al_2O_3 layer. Each point on the wafer see's the different gasses sequentially and by doing this the Al_2O_3 is grown by a deposition rate of 1nm/second. "In several trails we evaluated the quality by passivation effect in lifetime, charge density and uniformity", he clarifies. "We came to the conclusion that the quality of the Al_2O_3 effect was as good as temporal ALD, used in the semiconductor industry which has a deposition rate that is about 30 times slower. From that point on we knew that the spatial ALD from SoLayTec would be the right way to make low cost ALD for PV feasible."

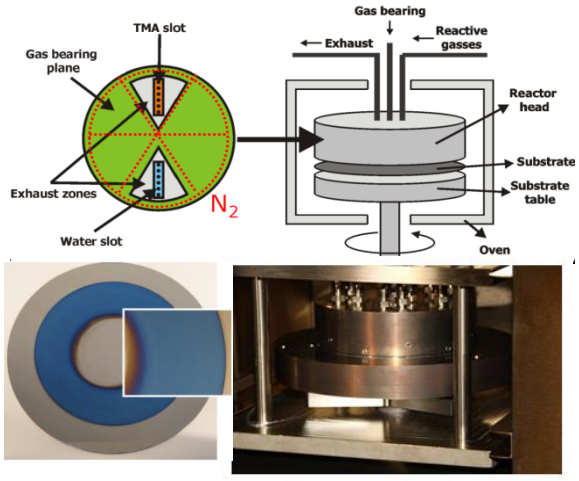

Figure 1, Rotating spatial ALD reactor

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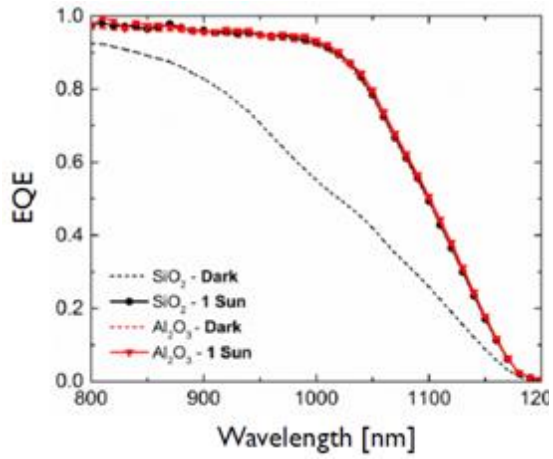
Letter of intent

Imec was the first company that signed the Letter of Intent, which was needed to setup the SoLayTec company. In this period the SoLayTec employees convinced us not only by the principle of the spatial ALD method, but also how to transfer this method into mass production. "In August 2011, we got the InPassion LAB tool at imec in Leuven and we started to use the tool in our program. Within several months of research in our affiliation program, we got excellent results on PERC efficiency records. At the end of 2011, the first record of imec was revealed and it had an efficiency of 19,6% on mono cSi material including annealing process to prevent the blistering after firing process. Subsequently, we co-developed the integrated anneal recipe with SoLayTec, which is currently used in the SPECTRUM PECVD of Tempress Systems." This recipe enables to skip the separated annealing furnace, so you can combine annealing and PECVD SiN_x capping layer in a direct PECVD furnace. During further research by imec, External Quantum Efficiency (EQE) data of p-type PERC passivation Al_2O_3 were compared to SiO_x. These data (see graph on the right) shows the SiO_x in the dark has low EQE at low illumination due to parasitic shunting of the floating junction induced by the positive fixed charges included in the SiO_x (and or SiN_x layer). When Al_2O_3 is put in direct contact with silicon no bias light dependency has been observed, because the negative charges in the Al_2O_3 layer are sufficient to prevent the formation of a floating junction at the silicon near surface. This ensures a higher energy yield over the year



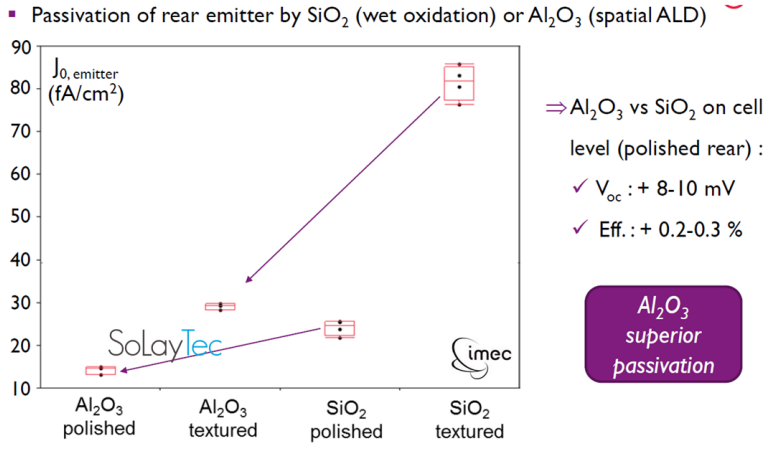
Graph 1, EQE data SiO_2 versus Al_2O_3

"In 2014, we started to focus on n-type developments like n-PERT and IBC structures. For both concepts it was always needed to do p^+ (n-PERT) and n^+ emitter (IBC) passivation by wet thermal oxide processing. But the duration of this passivation method, the higher thermal budget associated with oxidation and, last but not least, the inferior passivation properties as compared to ALD Al_2O_3 made us gear to the latter"

n-PERT H-Pattern cells with Rear emitter and front Cu contacts

The Al_2O_3 can be used for all three n-type cell concepts to passivate the boron emitter. Best record cell efficiencies made in 2015 by imec n-PERT. Especially, for textured n-type silicon wafers with boron emitter, excellent J_0 emitter values are reached for Al_2O_3 of 30fA/cm2 as compared to 80fA/cm2 for SiO_x. This leads in solar cell efficiency level to an absolute increase of 0,2% to 0,3% caused by an increase of open circuit voltage of 8mV to 10mV, respectively, allowing us to reach 22.5%. Besides the passivation of the boron emitter, Al_2O_3 can also be used as direct passivation of low doped n-type silicon.

	Jsc (mA/cm²)	Voc (mV)	FF (%)	Eff. (%)	Remark
Average	39.6	683	80.4	21.7	In-house measurement
Best cell	**39.9**	**684**	**80.7**	**22.0**	ISE CalLab calibrated meas.
Latest result	**40.3**	**689**	**80.9**	**22.5**	ISE CalLab calibrated meas.



Overview 1, n-PERT concept using SiO_x or Al_2O_3

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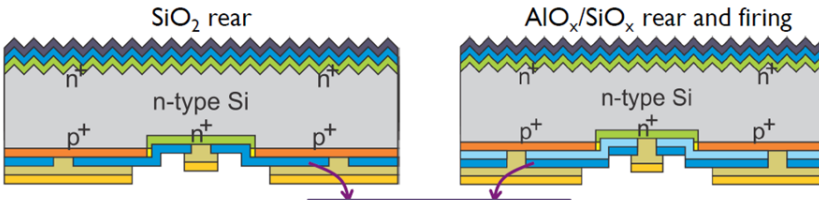
IBC cells using Al_2O_3 and copper plating

During the PVSEC conference in Munich 2016 imec presented also the latest results of n-type IBC cells of 22.8%. As mentioned before, ALD Al_2O_3 has proven to be a good passivation material for p^+ emitters. "In this work the ALD from SoLayTec plays a crucial role to passivate the p^+ emitter", Jef Poortmans continues. "Formerly, standard passivation method was done by using Wet thermal SiO_x. For IBC concepts the gain is +0,3% by using the ALD Al_2O_3 layer. This gives a wider opportunity to use our ALD system for all high efficiency cell concepts."



Best cells	J_{sc} [mA/cm²]	V_{oc} [mV]	FF [%]	η [%]
Baseline - SiO_2 rear	41.1	683	80.2	22.5
AlO_x/SiO_x rear and firing	41.2	688	80.3	22.8

Overview 2, IBC concept using SiO_x or Al_2O_3

According to Jef Poortmans the recent 5 year cooperation with SoLayTec on development, characterization and cell records with their spatial ALD was a great experience. "We are certain that for new high efficiency cell concepts surface passivation with very low surface recombination velocity will be essential. I am convinced that spatial ALD technique which SoLayTec has been pioneering has a bright future ahead", he concludes.

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