Fast ALD revolutionizes solar cell manufacturing

A novel disruptive concept in Atomic Layer Deposition (ALD), developed by Dutch research organization TNO, can achieve breakthrough ultrafast Al_2O_3 deposition rates of 1 nm/s (currently limited to 0.1 nm/s). Using spatial ALD, instead of temporal (i.e. time-switched) ALD, TNO researchers deposit 30 nm of Al_2O_3 in 30 seconds. Compared to 20 minutes in an R&D single-wafer reactor, this opens up a wide range of industrial-scale applications with high industrial throughput and cost-effective manufacturing. A very promising application is to improve solar cell efficiency by depositing Al_2O_3 as a backside passivation layer.

In recent years, research institutes such as Eindhoven University of Technology, IMEC in Belgium and the German Fraunhofer Institute, have been working on backside passivation of Si solar cells. Backside passivation by Al_2O_3 deposition may increase a single cell's efficiency in absorbing energy. An observed increase in efficiency from 16% to 17% represents a 5-year leap on the solar industry roadmap, according to a TNO representative. He demonstrates the profitability: assuming a 60 MW/year solar cell manufacturing plant, the efficiency increase yields another 3,75 MW/year. At €1.25/Wpeak this generates M€4.7 additional annual revenue. With an estimated investment of M€4-5, return on investment is achieved within approximately 12 months.
An additional advantage of passivation is that it allows for thinner silicon wafers in solar cell manufacturing. Because of the high material costs of silicon, thinner wafers, besides efficiency improvement, is an important direction on the solar roadmap.

Too slow
So far, the main drawback was that there was no cost-effective high-volume production tool available for depositing Al_2O_3 with Atomic Layer Deposition. Currently, industrial ALD production is mainly used in high-end semiconductor manufacturing, where the key application is high dielectric constant gate oxides in CMOS transistors and DRAM trench capacitors, and where high throughput is not essential. With a 100 wafers/hr throughput, this process is too slow for solar applications, whereas the alternative, PECVD (plasma-enhanced chemical vapor deposition), yields a lower quality passivation layer, which spoils the efficiency increase. The new technology now offers a fast process for high-quality passivation, so TNO claims.

Time-sequencing
Conventional ALD is based on the time-sequencing of self-limiting half-reactions, each separated by purge steps; see Figure 1. In the case of Al_2O_3 deposition, alternatingly

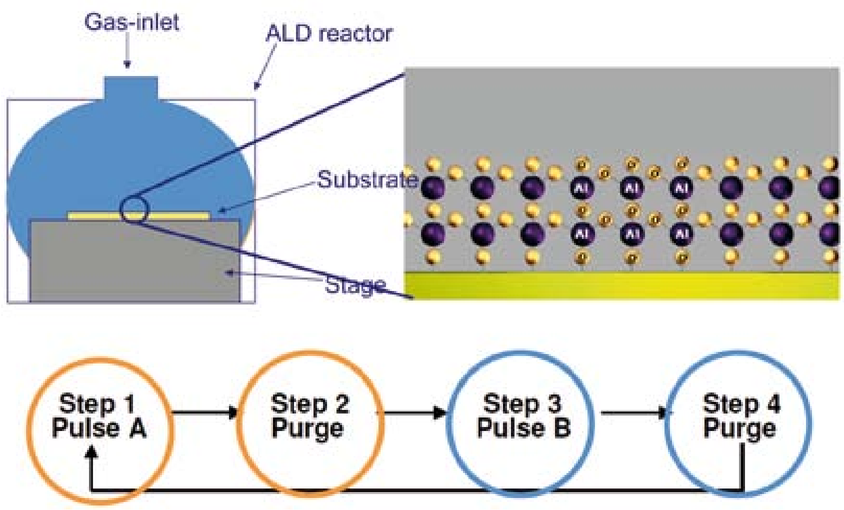

Figure 1. Schematic of Al_2O_3 deposition in a conventional ALD reactor.

trimethylene aluminum and water are exposed to the substrate/wafer, and as a result of two consecutive reactions (half-reactions), a single atomic layer of Al_2O_3 is deposited, after which the cycle can be repated for deposition of a second layer, etc.

Spatial separation

TNO's new ALD concept is based on spatial separation of these half-reactions: the reactor has separate zones, each exposing one of the precursors (in this case trimethylene aluminum and water) to a substrate. By rotating the wafer underneath the corresponding feeder nozzles, this spatial separation is translated into (periodic) time-sequencing. Gas bearings between the zones eliminate cross diffusion, hence there is no need for purge steps. An additional advantage of the gas bearing-based design is that it operates under atmospheric conditions, eliminating the need for vacuum loadlocks. Half-reaction timescales are

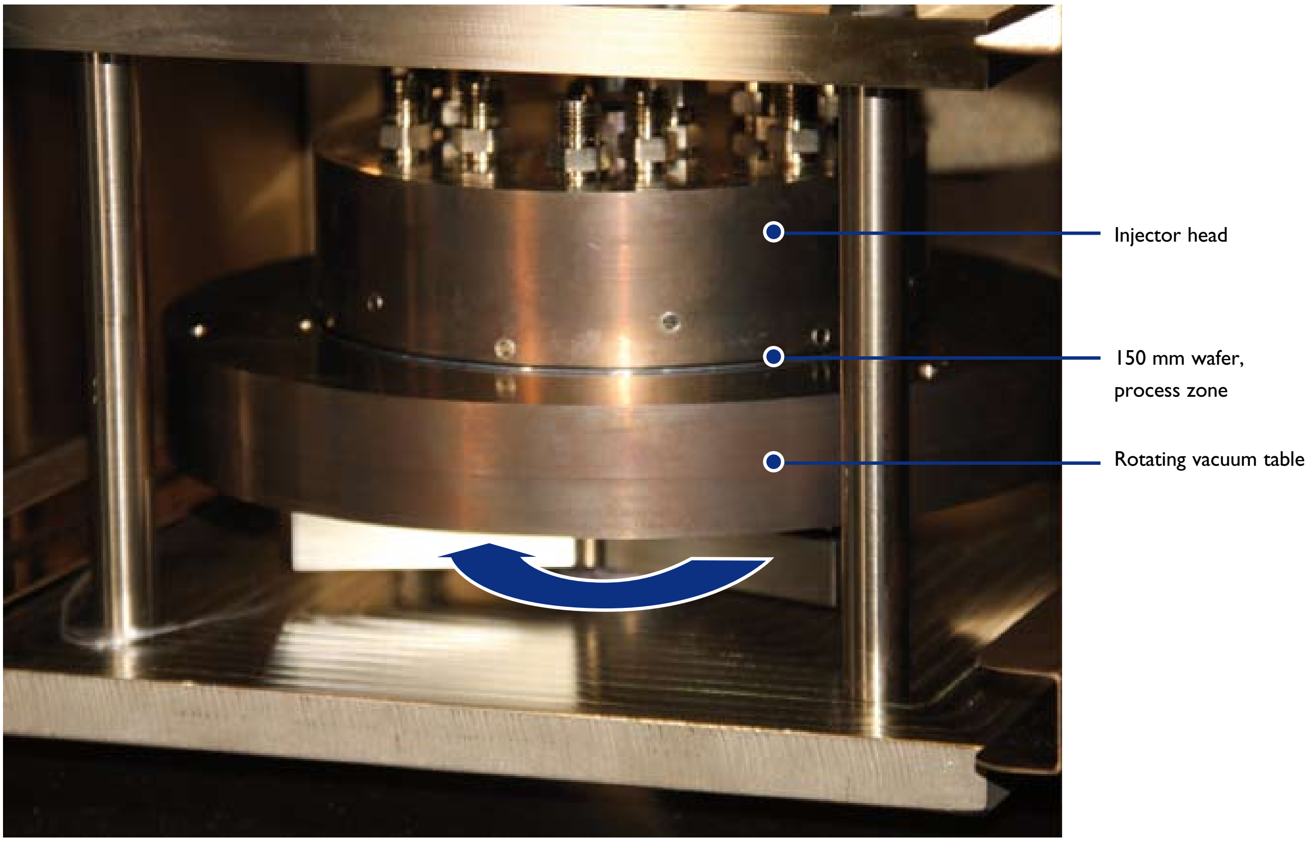

Figure 2. The ALD reactor for 150-mm substrates.

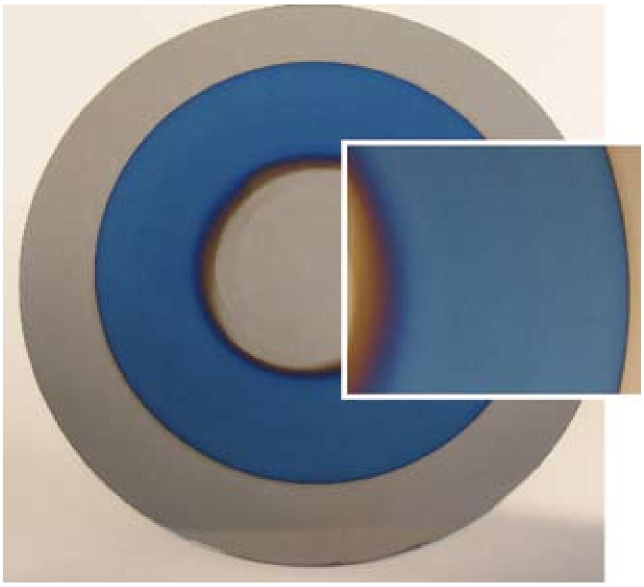

Figure 3. A 150-mm Si wafer with a 30-mm ring-shaped track of 100 nm Al_2O_3 deposition.

~10 ms, enabling ultrahigh deposition rates, while maintaining typical ALD film quality.

As a demonstrator, an ALD reactor was built that can handle 150-mm wafers. On a rotating vacuum table, a wafer is placed below a stationary injector head that contains the feeder nozzles for the precursor gases and the separation gas (nitrogen); see Figure 2. In one rotation of the table, a single layer is deposited, with a thickness in the order of 0.1 nm. At a moderate 600 rpm (10 rotations per second), the deposition rate is 1 nm/s. In fact, Al_2O_3 layer deposition rates of ≥1.2 nm/s have already been demonstrated. These films show excellent surface passivation; see Figure 3.

Linear set-up

For in-line industrial application, it is practical to replace the rotational process by a linear process. In that case, the substrate will move back and forth below the stationary injector head. The mechatronic solution for this linear set-up is one of the tricks of TNO's new ALD concept. An additional advantage, next to the higher industrial throughput (targeted at 3000 wafers/hr), of this industrial in-line solution is its small footprint (2.5 x 3 m^2), as compared to the alternative ALD set-up with a sequence of vacuum reactor chambers.

New applications

Ultrafast ALD will also open up new applications in the manufacturing of LEDs (deposition of buffer layers), organic LEDs (deposition of barrier layers), flat panel displays, sun-protection glass, and of course semiconductors. Al_2O_3 is more and more becoming an important material for many applications. For instance, to enhance the quantum efficiency of silicon in metal-insulator-semiconductor devices, to encapsulate humidity- or oxygen-sensitive materials and devices. Or to enhance the Q-factor of Si-based cantilevers to enable functionalization on hydrophobic graphene and carbon nanotube surfaces for application in nanoelectronics. Of course, also other binary, multi-component oxides and other compounds like nitrides, sulfides, coatings that are now being deposited by CVD, may soon transfer to a high deposition rate ALD production environment.

SoLayTec

TNO has already taken steps to develop cost-effective, high-volume production batch systems for solar cell manufacturing. Tests show throughput numbers for cost-effective production are feasible.
At the moment, all efforts are aimed at further maturing of the technology. For development towards industrial-scale production, a large R&D project has been set-up by TNO in collaboration with some eight companies within the Eindhoven region. Funding was solicited from the Dutch Ministry of Economic Affairs, Peaks in the Delta programme. For commercialization, a TNO spin-off company is about to start, called SoLayTec. Once more, perspectives are sunny for solar energy.

Note

This article was in part based on information published on the TNO website.

Information

roger.gortzen@tno.nl
www.tno.nl
www.solaytec.com