# Evidence for low-energy ions influencing plasma-assisted atomic layer deposition of $SiO_2$ as measured with Impedans' Quantum System

## INTRODUCTION

Silicon oxide is a ubiquitous material that has applications in fields such as nanoelectronics, photovoltaics and photonics to name a few. Due to the consistent downscaling of device features, processing techniques on the atomic-scale such as plasma assisted atomic layer deposition (ALD) are becoming increasingly important in the creation of nm-thin $SiO_2$ films. In comparison to thermally driven ALD, Plasma assisted ALD is relatively simple and can provide high quality $SiO_2$ with temperatures as low as 50 °C.

## EXPERIMENT

The Plasma assisted ALD of $SiO_2$ was carried in an Oxford Instruments FlexAL ALD system, which was equipped with a remote inductively coupled plasma (ICP) source operated at 13.56 MHz. Additionally, an external 13.56 MHz power supply could be connected to the reactor table to apply a substate bias. For all depositions, $SiH_2$ $(NEt_2)_2$ was used as the precursor and $O_2$/Ar plasma as the co-reactant, with plasma exposure times ranging from 3.8 s to 120 s per cycle.

Film growth was monitored with an [Impedans Quantum system], which contains a quartz crystal microbalance (QCM), allowing for the deposition rate to be monitored, where the flux of ions to the crystal could be controlled by varying the voltage applied to the grids embedded in the sensor. In order to compare the effect of the impact of ions to the effect of

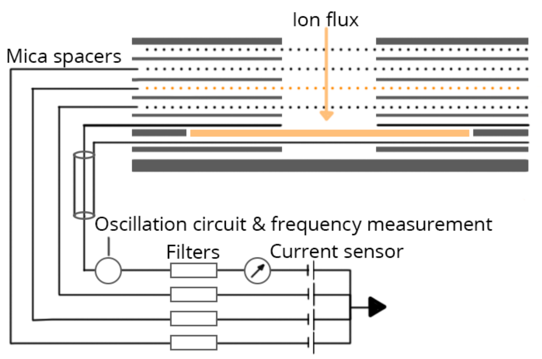


Figure 1. Schematic of the RFEA with integrated Quartz Crystal Microbalance (QCM) which allows the energy distribution of ions to be measured. The RFEA grids are also used to selectively block or transmit ions to the QCM to measure deposition rates of ions and neutral species.

temperature, depositions were carried out with substrate temperatures of 100, 200, and 300 °C, using 250, 400 and 250 ALD cycles per sample respectively.

## RESULT

Figure 1, illustrates how the RFEA grids completely block ($eV_d > E_{ion}$) or partly transmit ($V_d$=0) the flux of ions to the quartz crystal, where $V_d$ is the potential of the energy discriminator grid and $E_{ion}$ is the maximum energy of the ions. An example result is shown in figure 2, where the absolute change in the resonance frequency, which is proportional to the deposited mass, is plotted for 9 ALD cycles of $SiO_2$ with and without ion transmission. The slope represents the growth per cycle in terms of the mass per cycle, which in turn represents the thickness per cycle as the mass density is approximately unaffected.

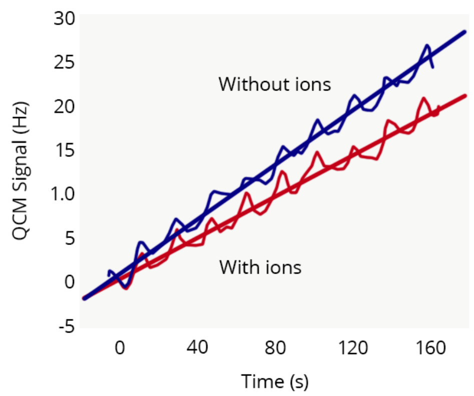


Figure 2. Results obtained for the plasma assisted ALD of $SiO_2$ which shows that the growth per cycle (GPC) is reduced upon exposure to ions.

Under the plasma conditions used, 100 °C and ~ 19 mTorr, 100/50 sccm $Ar/O_2$, 600 W ICP power, 10 W bias and 5 s plasma steps, the GPC was reduced by 22 Å ± 7% when exposed to ions compared to the value obtained without ion transmission.

Data corresponding to different experimental conditions is given in figure 3, which reveals that the ion energy dose appears to determine the influence of the ions on the growth. The ion energy dose (Ion flux*Plasma Exposure time*Mean ion energy) was estimated based on the RFEA measurements. Figure 3 can serve to compare reactors and processing conditions that can be very different from each other. It also shows that the effect of the ions on the plasma assisted ALD, of $SiO_2$, is negligible when supplying an ion energy dose lower than ~ 3 eV $nm^{-2}$ per cycle. In contrast to this, the growth is significantly affected when the ion energy dose is ≥100 eV $nm^{-2}$ per cycle. This effect will only be obtained on surfaces undergoing ion impingement, e.g. the side walls of trench will not be affected. The deposition rate monitor QCM measurements confirm the trend.

## CONCLUSION

In conclusion, it was demonstrated that ions have a stronger impact on the plasma ALD of $SiO_2$ than usually considered. Even low energy ions (<20 eV) can significantly influence the GPC and therefore the material quality, where the magnitude of this influence can be predicted by the supplied ion energy dose. This work provides valuable insights into how to tailor $SiO_2$ film growth by ALD in state-of-the-art and

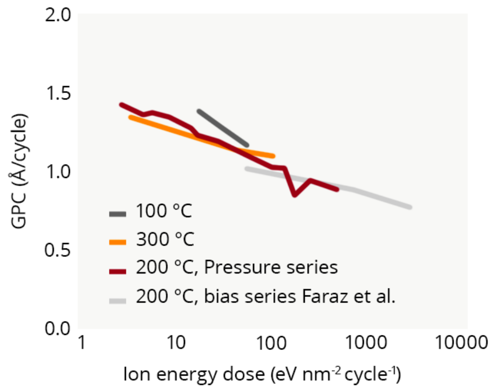


Figure 3. GPC of $SiO_2$ grown with ion exposure, showing a clear trend with the supplied ion energy dose as measured by an RFEA. The ion energy dose was varied by using different plasma pressures and exposure times (in this work), along with substrate biasing (Faraz et al).

next generation device applications.

## REFERENCES


*Arts K. et al, "Evidence for low-energy ions influencing plasma-assisted atomic layer deposition of $SiO_2$: Impact on the growth per cycle and wet etch rate".

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