From Dense to porous SiO_x Thin Films Deposited under Atmospheric Conditions for Various Industrial Applications

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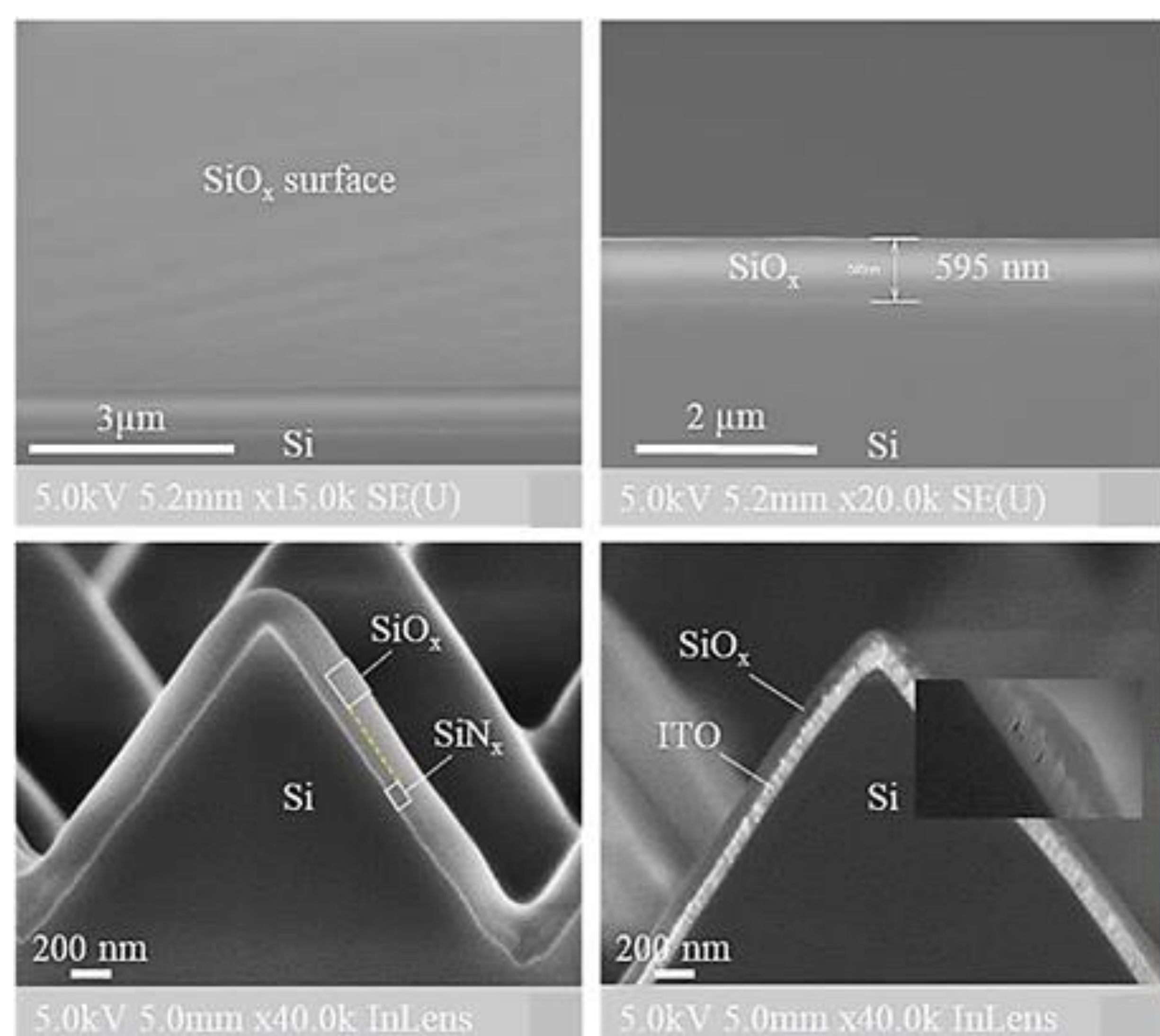
A cost-effective, yet robust and high-throughput atmospheric pressure chemical vapor deposition (APCVD) system was developed to serve for thin-solid film preparation at room temperature. The APCVD system was anteriorly approved for SiO_x nano-microlayers in various industrial applications.

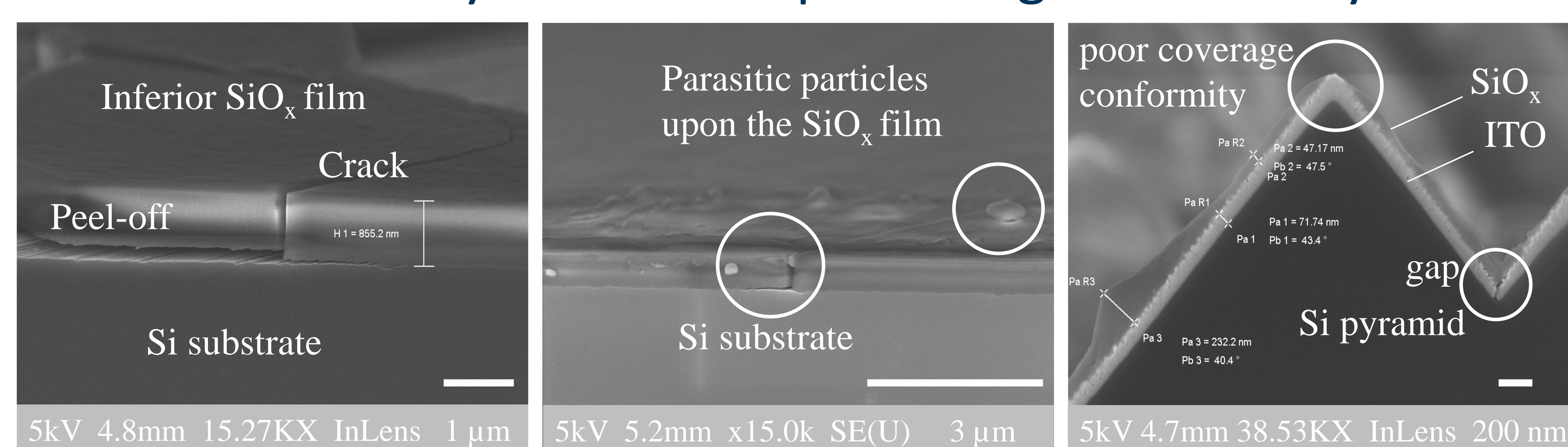


SEM of various cross-sections of SiO_x films coating different Si surface structures conformally. The films are dense without embedded contaminants, cracks, or interface gaps. The yellow dashed line in the bottom left figure is a guide for the eye between the SiO_x and SiN_x layers.

Deficiency & Problem

Conventional APCVD of SiO_x possesses numerous drawbacks

- Hazardous and flammable reactants such as SiH_4 and N_2O
- High thermal budget required to activate the reaction
- Considerable pores and pin-holes integrated into the film
- SiO_x contaminants embedded upon the film surface
- Chemical non-stoichiometry and material impurity
- Non-uniformity and low step-coverage conformity



Motivation & Challenges

Low-cost and functional SiO_x films for various industries

- Room temperature APCVD utilizing safe chemicals
- Film density aligning with that of thermal SiO_2
- Optionally, porous film structure to act as an interlayer

Major challenges:

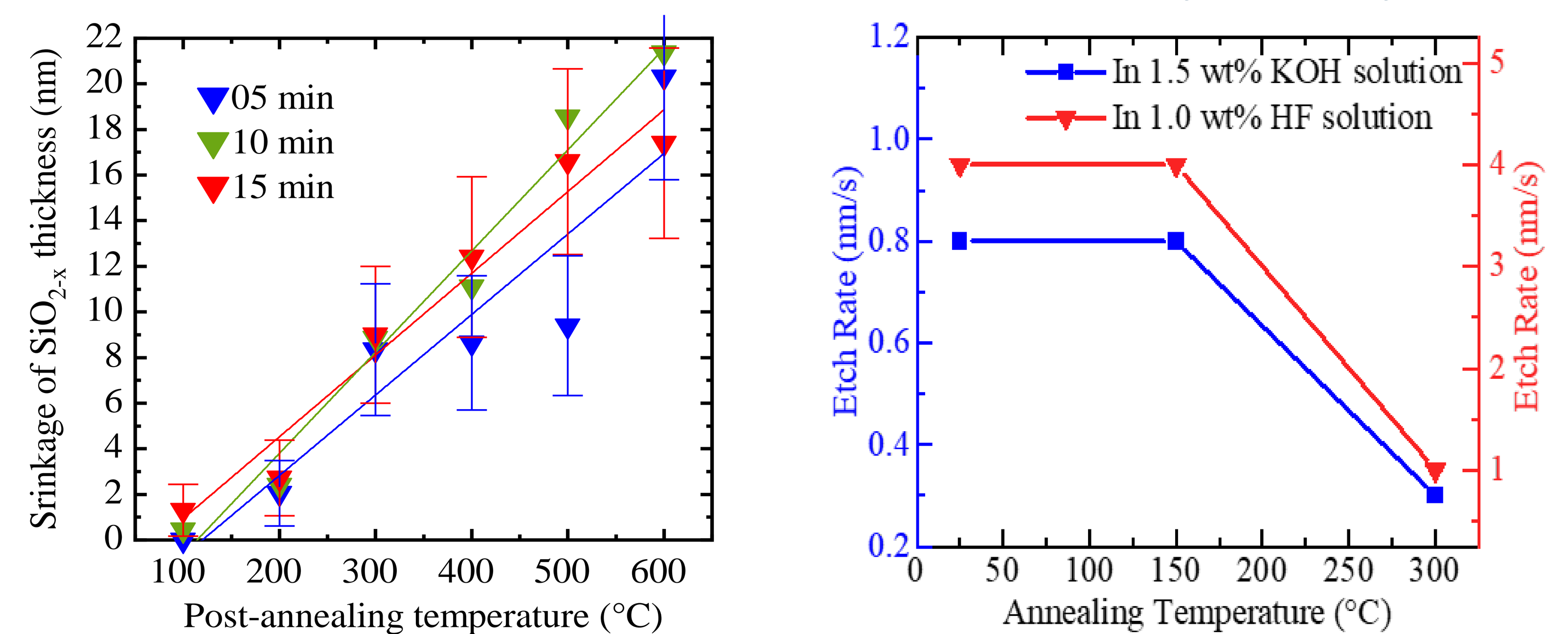
- Predomination of the surface reaction-driven APCVD
- Intimate adherence to nearly every surface material
- Conformal coverage with no particle contamination
- Resilient structure with no defects after annealing
- Chemical stoichiometry with no impurities

Methodology & Experimental

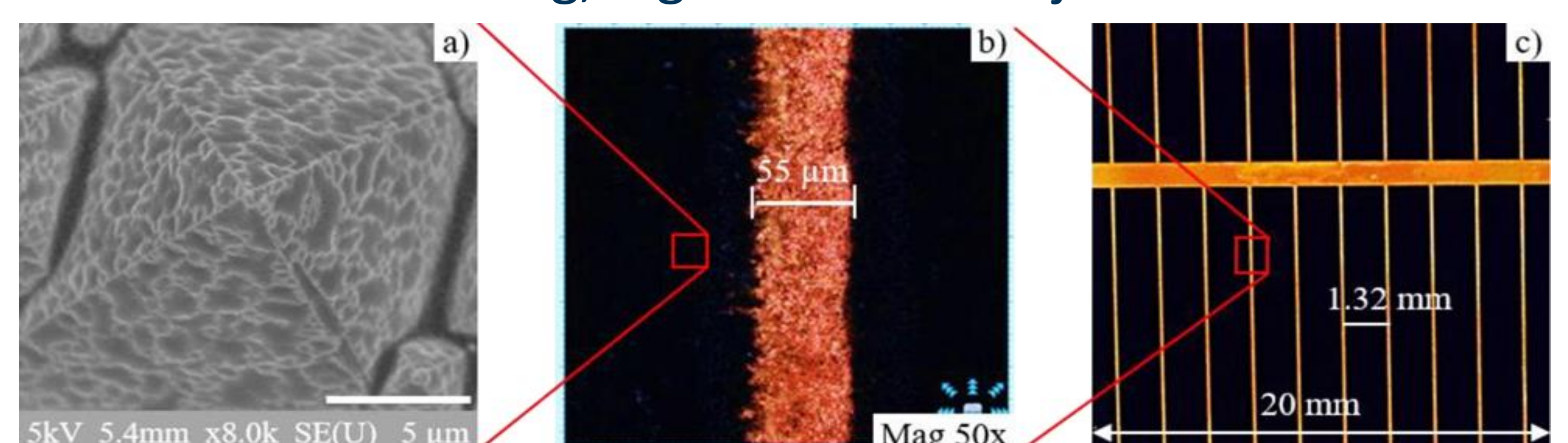
- APCVD apparatus is 3D printed from polylactic acid.
- Reactive gases are introduced to the apparatus and collide with the intended substrate surface placed inside.
- Depending on the operating boundary conditions and the desired film characteristics, the deposition rate varies from 1 to 245 nm/min.
- For harsh applications, the SiO_x films can be post-treated at 200 – 400 °C for 1 min, hence structure relaxation.
- The operation costs are calculated 1 $Cent per 100 nm thick film coating a 6-inch wide substrate.

Results & Findings

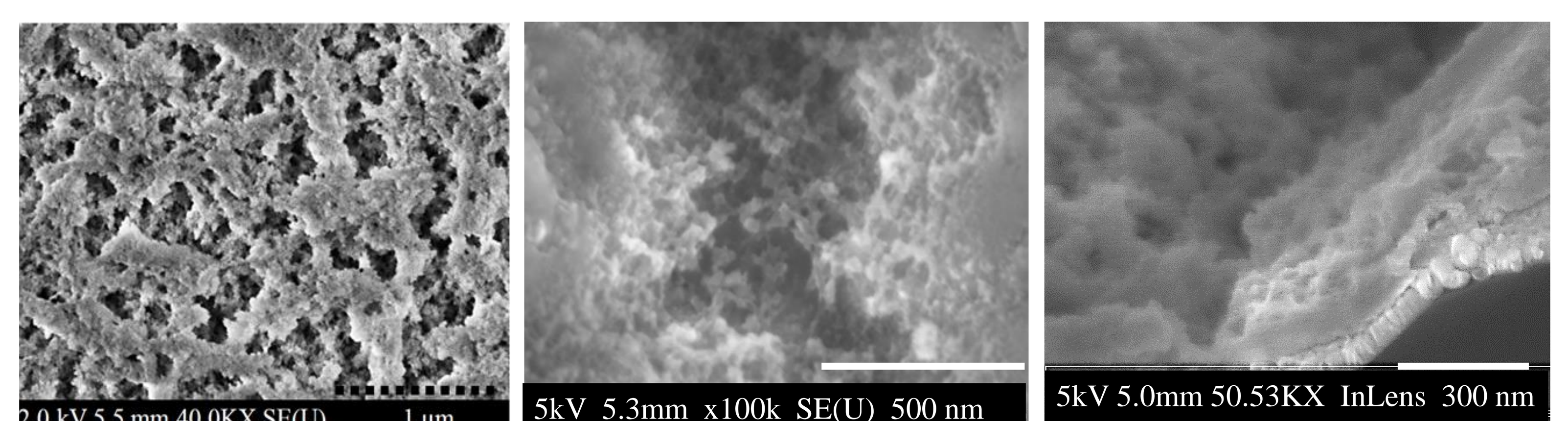
- The APCVD SiO_x films demonstrated high stability against annealing temperatures (T_a) up to 900 °C for 60 min.
- Depending on its duration, annealing at elevated T_a led to shrinking the film thickness by a ratio of 0.6 - 12.5 %.
- Annealing the as-deposited films at $T_a \geq 300$ °C caused decreasing the etch rate in 1.5 wt% KOH and 1.0 wt% HF solutions down to 0.3 nm/s and 1 nm/s, respectively.



- The APCVD SiO_x films were proven to perfectly serve as an insulating mask against the electroplating currents used for metalizing, e.g. silicon heterojunction solar cells.



- Another option was to successfully obtain porous, yet resilient SiO_x films to act as an anchor for overlying layers employed in microelectronic and automotive industries.



Bibliography

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