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Very Fast Silicon Deposition with High Speed Jet in SiH_4/ H_2 PE-CVD

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Background

・Silicon thin film (micro crystalline silicon (μ-Si) and hydrogenated amorphous silicon (a-Si:H)) is major material in semiconductors, e.g. thin film solar cells.

・Plasma Enhanced Chemical Vapor Deposition (PE-CVD) in SiH_4/H_2 is utilized to obtain silicon thin film.

・In standard PE-CVD, deposition rate is several nm/s, and high deposition rate is desired for short deposition time.

Previous Researches

・Sobajima et al. (2008) obtained a deposition rate of 8 nm/s at 2700 Pa with a RF power of 2.2 W/cm². Such methods have been hypothesized to be mass-transfer limited because the diffusion constants decrease at higher pressures.

・Kuribayashi et al. (our group, 2013) developed a process for high-rate hydrogenated silicon deposition that is controlled by the conditions of gas flow. The experimental results showed that localized Si:H deposition occurs at over 1 μm/s when using an underexpanded supersonic jet at a background pressure of 800 Pa without a capillary, and excited at 60 MHz, 0.8 W/cm².

Objective

・To investigate the mechanism behind such high-rate deposition, We investigate how deposition rate and shape of the deposited hydrogenated silicon depend on gap distance and mass-flow rate on the deposition rate.

・We also use computational fluid dynamics (CFD) calculations to analyze how gas flow affects high rate hydrogenated silicon deposition.

・We try combination of the jet CVD and dynamic deposition proposed by Sugai.

Methodology

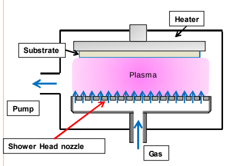


Fig. Standard PE-CVD setup (for comparison)

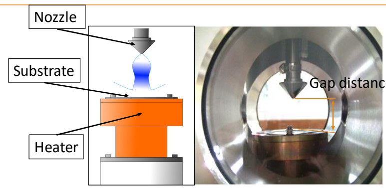


Fig. Setup of our system

・Both the nozzle and the heater are electrodes.

・Sample gas is injected through a hole at the vertex of the nozzle.

・The gas flow becomes underexpanded supersonic jet.

Typical experimental conditions

Back groud pressure	800 Pa
Inlet pressure	6.6×10⁴ Pa
M.F.R. of H_2	100～1000 sccm
M.F.R. of SiH_4	1～10 sccm
Temperature	200 °C
Gap distance	h= 1～20 mm
Nozzle diamete	0.3 mm
VHF Frequency	60 MHz
Input power	45 W
Deposition time	30 min

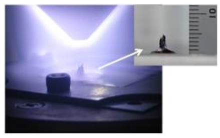


Fig. Picture during deposition

Results (gap distance dependence)

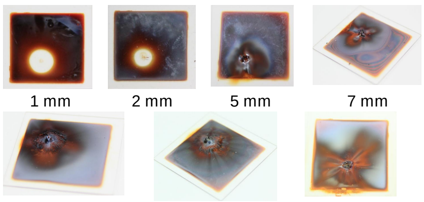


Fig. Deposited film at several gap distances

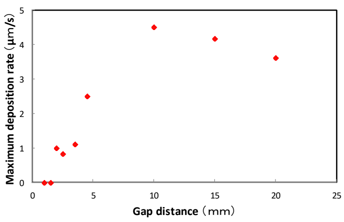


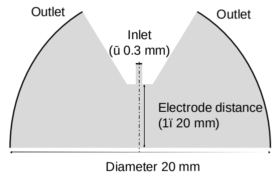
Fig. Plot of deposition rate and gap distance

・Deposited silicon structure changed depending on the gap distance.

・Very thin deposition under the nozzle, when the gap distance was < 2 mm.

・Local deposition was observed, when the gap distance was >5 mm .

CFD calculation



・CFD calculations based on FLUENT 14.0 (ANSYS Inc.) were used to simulate the impinging jets

・These calculations were performed using 2-D axis symmetry, and shear stress transport (SST) k–ω as a turbulent model. Double-precision and upwind-difference schemes using primary accuracy were also used.

Number of cells : 41,000

Inlet pressure : mesured value in each experiment

Outlet pressure : 800 Pa

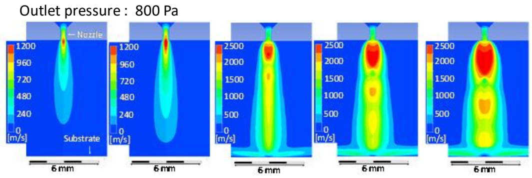


Fig. Calculated velocity

Results (mass flow rate dependence)

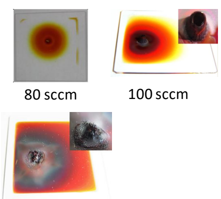


Fig. Deposited film at several mass flow rate

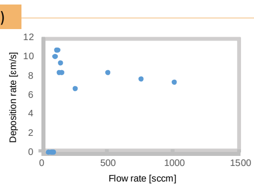


Fig. Deposition rate as a function of mass-flow rate

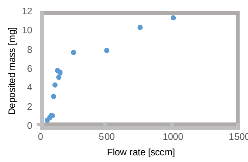


Fig. Mass of silicon deposited as a function of mass flow rate

・The deposition rate is very low with a mass-flow rate ≤ 90 sccm, but rapidly increases to a maximum for mass-flow rates of 110 and 120 sccm. Beyond this point, the deposition rate decreases slightly, and remains almost constant between 250 and 1000 sccm, though the deposited mass monotonically increases as a function of the mass-flow rate.

Discussion

・The results of these CFD calculations indicate that the jet velocity near the substrate increases with the inlet mass-flow rate. This can be explained by turbulence that is generated by an increase in the jet-gas velocity in low vacuum, which in turn promotes convection and increases mass transfer.

・Although the jet shapes at 80 sccm and 100 sccm are similar to each other, the shapes of the localized deposits are far more different. Although the reason for this discrepancy is not clear, it may be caused by a collaborative effect between chemical reactions and gas flow inside the chamber.

Dynamic deposition

To obtain uniform deposition, combination of Jet CVD and dynamic deposition, proposed by Sugai (2010), was tested.

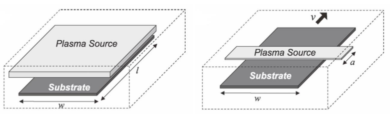
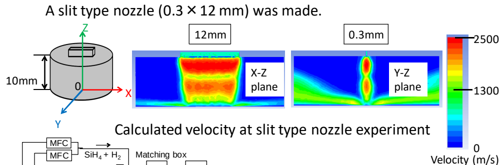


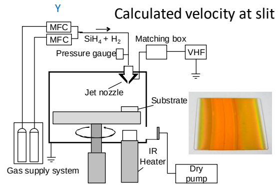
Fig. Schematic diagram of dynamic deposition from Sugai (2010)

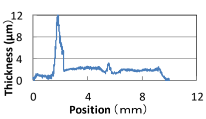
The substrate moves relative to the fixed plasma source, whereas in the standard deposition process, the positions of the plasma source and substrate are fixed. Dynamic deposition has been considered to be an effective method for fabricating flexible solar cells.

A slit type nozzle (0.3 × 12 mm) was made.



Calculated velocity at slit type nozzle experiment





・Uniformity was improved.

・Peaks was observed at the center and edges of the deposition.

・Nozzle design is important for better uniformity

Conclusion

・A high-rate silicon-deposition process was developed based on a high speed jet, in which the mass-flow rate was found to significantly influence the deposition process.

・This proposed high-rate deposition process requires only ~1 W/cm² of VHF power to achieve deposition rates of 1 μm/s, which is much less power than is required by thermal-plasma-jet processes.

・This process is quite similar to conventional PE-CVD processes, and therefore requires little additional investment to implement. A better understanding and control of the proposed process will require further experimentation and analysis into its unique jet flows, plasma conditions, and chemical reactions.

・Combination of dynamic deposition and the developed CVD process can be effective for uniform deposition with high deposition rate, but more improvement of nozzle design is necessary.

Reference

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・Sugai, H.; "Frontier of Development of Large-Area Plasma CVD Processing" (in Japanese), *J. Plasma Fusion Res.*, 86, 28-32 (2010)