Spatial structure of plasma potential oscillation in VHF multi-tile electrode plasma source

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Abstract

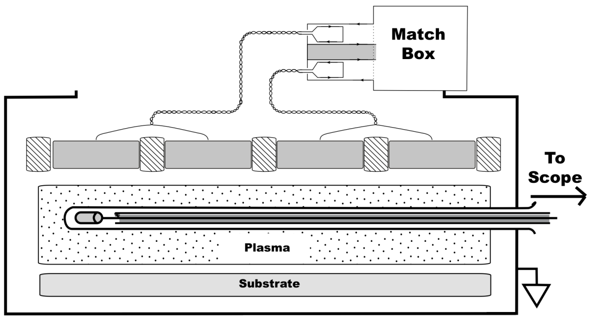
Increasing RF frequency in the VHF range in the PECVD of Silicon in thin film photovoltaic manufacturing process enables a higher rate of deposition while maintaining film quality[1, 2]. However Plasma uniformity on large substrates is compromised as wavelength effects are encountered at high frequencies [3]. Using a segmented electrode consisting of individual tiles each 180° out of phase with adjacent tiles, a scalable VHF source that is not affected by wavelength effects is achieved. Due to the 180° phase shift between tiles, a spatial structure is imposed on the plasma. In this paper, we investigate the spatial structure by examining the plasma potential oscillation. Data taken with capacitive probe measurements, of the phase and amplitude of the plasma potential oscillation as a function of position in the plasma is presented. It is expected that spatial structure will be more prominent for the fundamental and odd harmonics of the plasma potential oscillation. While there should be little or no spatial variation of even harmonics. A discussion of the measured profiles is presented.

Introduction

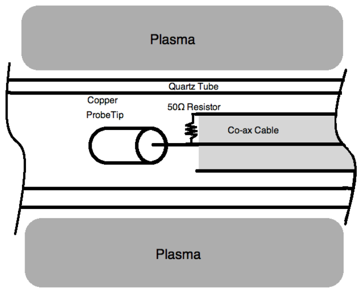
Capacitively coupled radio-frequency glow discharges are commonly used for the deposition of materials by plasma-enhanced chemical vapor deposition (PECVD). Deposition over large area substrates by PECVD processes is of particular interest to the photovoltaic industry. It has been shown that by increasing the driving RF frequency in the VHF range more power can be coupled into the plasma and thus an increase in the rate of deposition is observed while at the same time maintaining desirable material quality [1, 2]. However as substrate sizes increase, quarter-wavelength effects are encountered as the geometry and size of the electrode and chamber are now comparable to the wavelength of the driving RF voltage. As a result of these quarter-λ effects, a significant degradation of solar cell performance is observed [3]. For example deposition uniformity, band gap and cell efficiency all suffer a drop in quality. Using a Capacitive probe to measure the plasma potential oscillation provides a good indication of how currents flow from within the plasma to a grounded substrate thus furthering our understanding of the deposition process.

Multi-Tile Plasmas

Rather than using a large area single electrode that is susceptible to wavelength effects, the source used in this experiment is a segmented electrode that is divided into multiple tiles. As shown in Figure 1(a) (below) neighboring tiles are powered 180° out of phase with each other.



(a)



(b)

Figure 1: a)Cross section of the plasma source showing the tile configuration of a multi-tile segmented electrode glow discharge source, and b) Schematic of capacitive probe in a quartz tube

Because the individual tiles are small in size (10x10cm) their dimensions are much smaller than the RF wavelength of the driving RF voltage. Thus, a scalable VHF source that is not affected by wavelength effects can be achieved.

Capacitive Probes

A capacitive probe consists of a coaxial cable with a cylindrical copper tip attached to the inner conductor.A small 50Ω resistor connects the inner core to the outer conductor as shown in **Figure 1(b)** The probe is then placed in a re-entrant quartz tube located in the plasma. The probe is free to move along the length of the quartz tube. Due to concerns regarding the plasma coupling to the outer conductor as well as the probe tip, a semi-rigid triax cable was used in this experiment. The outer conductor was grounded thereby shielding the two inner conductors from the plasma, leaving only the probe tip exposed.

The oscillation of the plasma potential couples to the exposed probe tip. As a result, the measured voltage across the 50Ω resistor in the probe provides us with a representation of the plasma potential oscillation. This measured signal consists of the fundamental RF frequency (162MHz) and second and third harmonics (324MHz, 486MHz).

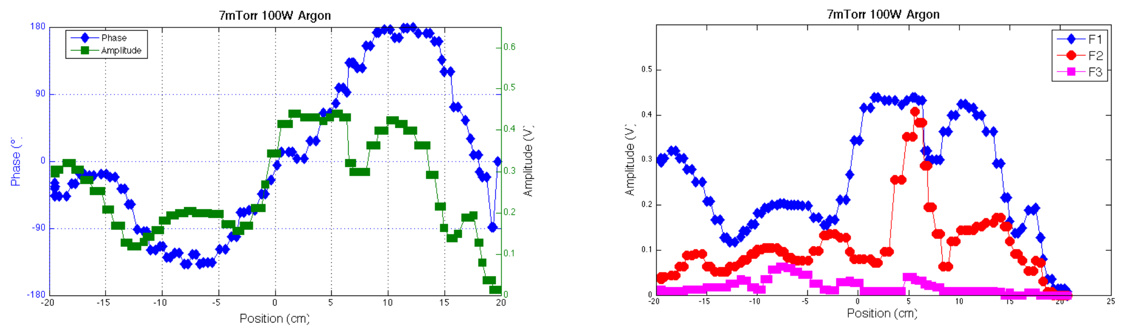
Experiment

Measurements are carried out using a multi-tile glow discharge source with each tile driven differentially by a power splitting device powered by an Advanced Energy 162MHz RF generator. Argon plasma are primarily investigated however Oxygen and Nitrogen are often used also. Capacitive probe measurements of the phase and amplitude of the plasma potential oscillation of the plasma are taken for a range of RF powers (100W - 1500W) and pressures (5mTorr - 500mTorr) at a distance of 6cm from the electrode face. Data was acquired using a Tektronix scope connected to a PC running LabView via a GPIB connection.

Results

Plots of Phase and Amplitude of the plasma potential oscillation as a function of position in the plasma were compiled. From **Figure 2** it is clear that there is a definite spatial structure to both the phase and amplitude of the plasma potential oscillation.

Examining the fundamental oscillation first, we see that the phase changes by approximately 180° from tile to tile.



(a) (b)

Figure 2: Plot of the phase and amplitude of the fundamental (a) and comparison of the amplitudes of the fundamental, second and third harmonics(b)

However this change in phase is not as sharp as had been expected. It is thought that currents within the plasma tend to smooth out the plasma potential oscillation far from the tile. In addition to this, as pressure increases, the tile-to-tile phase shift is observed to decrease.

The amplitude of the second harmonic peaks above tile boundaries and is at a minimum above tile centers. The phase shift of the second harmonic compared to the fundamental is less prevalent, however a slow smooth change of phase across the chamber has been observed, indicating that the second harmonic has less spatial structure.

The third harmonic although less prominent than the first and second, appears to be at a maximum above tile centers and at a minimum above boundaries. Phase data, follows the pattern of the fundamental harmonic and shows a phase shift of approximately 180° between tiles as expected.

Conclusion

Capacitve Probe measurements show the relationship between plasma potential oscillation and position for a high frequency multi-tile discharge. Results show that there is a clear correlation between the both the phase and amplitude of the plasma potential oscillation and the electrode configuration as expected.

References

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