Materials processing with the expanding thermal plasma technique using controlled ion flux and energy

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Materials processing using energetic ions that are extracted from a plasma with a bias voltage is frequently used nowadays. The reason is that energetic ions can activate non-thermal processes at the surface and that the directionality of the accelerated ions can lead to an anisotropic reaction.

A separate power source is needed in a remote plasma configuration, where it is important that the substrate bias does not influence the plasma properties. However, this is not always achieved with the widely used 13.56 MHz sinusoidal substrate bias. The ion flux can depend on the substrate bias conditions because the high frequency leads to efficient electron heating. This effect is particularly strong in the expanding thermal plasma where the average, thermal electron energy is only about 0.3 eV. Moreover, it is desired that a well-defined ion energy is obtained. However, a bimodal ion energy distribution is obtained with the 13.56 MHz sinusoidal substrate bias. The energy separation between the two peaks decreases with frequency but a frequency of 13.56 MHz is not always high enough especially in high-density plasmas.

To offer a solution for the above-mentioned drawbacks, we have constructed a dedicated power source, which is capable of delivering a negative square wave potential to the substrate at frequencies below 100 kHz and with a duty cycle above 90% [1]. As a result of the low frequency, relatively little power is lost in heating of the electrons and through parasitic effects. Furthermore, the pulse-shaped waveform can result in a mono-energetic ion flux to the substrate because the ion plasma sheath transit time is much shorter than the waveform period for most plasma conditions. In addition the pulse-shaped bias provides a direct monitoring of the ion flux towards the materials processed, enabling direct insight into the nature of the etching or deposition process.

The dedicated power source was applied successfully to the expanding thermal plasma technique for both deposition and etching processes. It was demonstrated that the specific ion energy and the controlled ion flux obtained with the dedicated power source have definite advantages over other forms of substrate bias. Two examples of this novel substrate bias method will be given. First, the densification of silicon dioxide deposited at a substrate temperature of 50 °C was investigated as a function of ion energy. Second, the anisotropic etching of silicon in a fluorine-based and time-multiplexed plasma was achieved with a selectivity of more than 900 due to the good ion flux control.

[1] S.-B. Wang and A.E. Wendt, *J. Appl. Phys.*, **88**, 643 (2000).