Metrology for in-situ industrial plasma processing

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MOTIVATION

Due to demand for improved computer processing power, feature sizes of semiconductors have significantly reduced to the scale of nanometres. In order to fabricate these dimensions, low temperature plasmas are used. In particular, the ions and reactive species that are produced from non-equilibrium plasma are used in etching of surface features, attaining high levels of precision. Nonetheless, in order to improve manufacturing processes, it is important to understand the interaction between the plasma and material surface [1]. So, to better control and design the plasma, real-time sensors that probe the plasma-surface interface are critical into achieving atomistic precision in plasma processing applications [2].

PROJECT WORK

This project builds on a sensor design concept being developed to probe the plasma-surface interface. Proof of principle has been demonstrated and within this project the metrology concept will be adapted and implemented as a real-time sensor for process control. Plasma operating conditions common to processing applications and divertor regions will be investigated, namely molecular electro-negative gases e.g. hydrogen and oxygen.

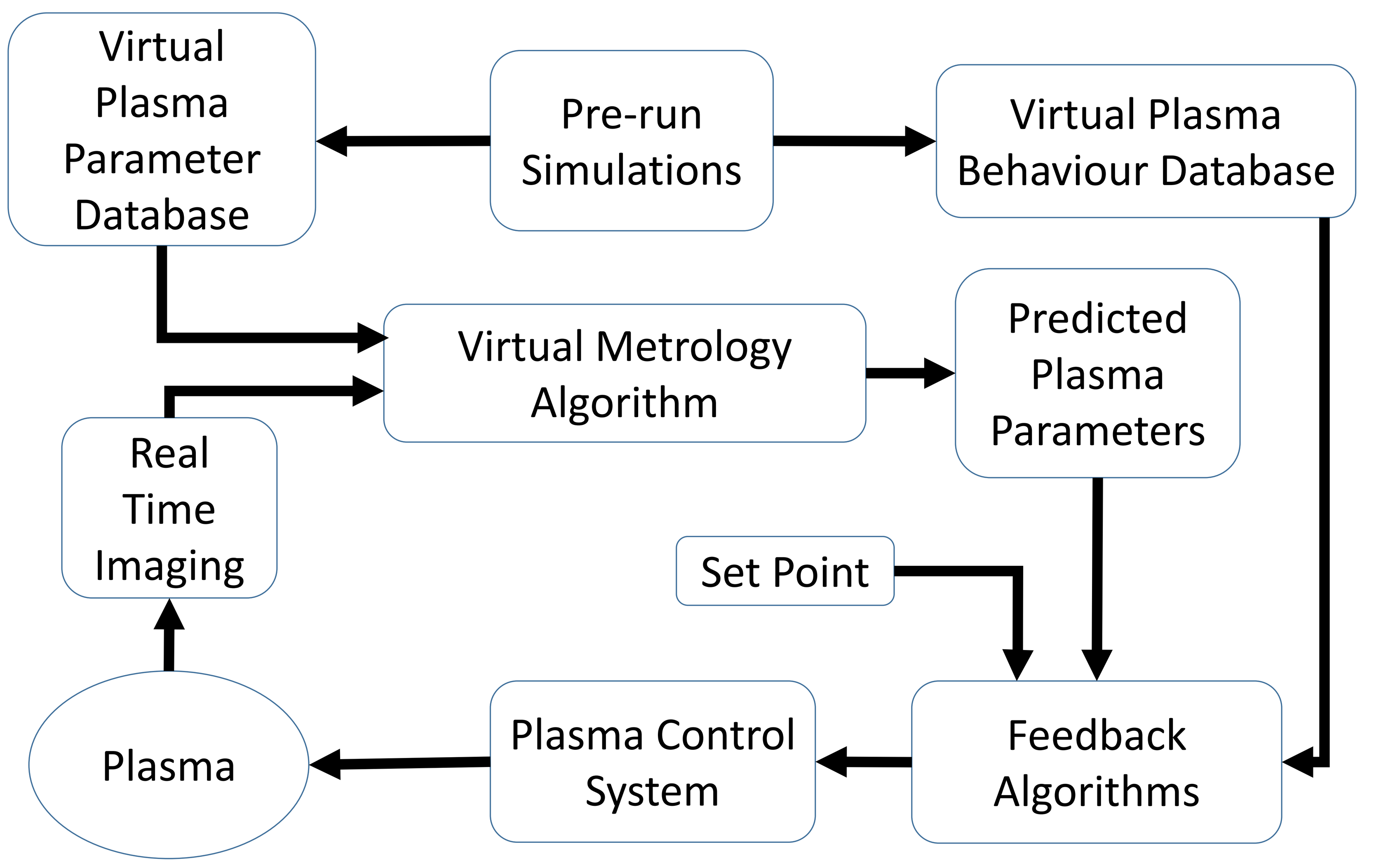


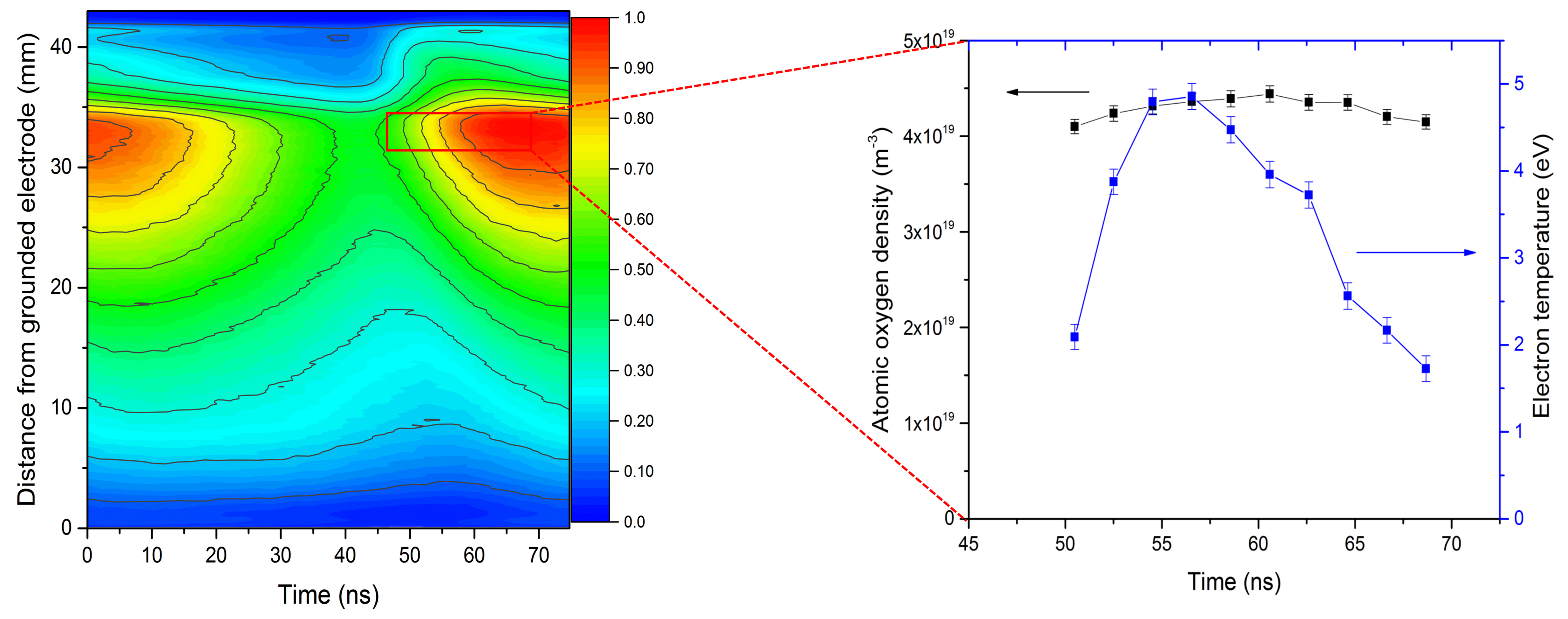
Fig. 1: The proposed Virtual Metrology Algorithm flowchart to improve manufacturing precision. The sensor images the plasma in real-time and, together with known data, feedback mechanisms can act to adjust the plasma properties as needed.

ENERGY RESOLVED ACTINOMETRY

- Energy Resolved Actinometry (ERA) is an example diagnostic technique that can give important information about the plasma.
- By taking the ratio between the intensity of the emissions of the tracer gas, argon and the excited atomic oxygen states to determine its densities by using a balance equation (right) as well as the electron dynamics [3].
- Emission lines taken at Ar 750, O 844 and O 777 delivers 3 sets of images, 37 per rf cycle at 13.56 MHz, 2 ns gate width.
- Each image has a resolution of 1024 x 1024 pixels, providing a large amount of data that can be analysed and improve understanding of the plasma dynamics.

$$n_O = \frac{I_O}{I_{Ar}} \frac{h\nu_{Ar}}{h\nu_O} \frac{k^*_{Ar,d}}{k^*_{O,d}} \frac{a_{ik,Ar}}{a_{ik,O}} n_{Ar} - \frac{k^*_{O,de}}{k^*_{O,d}} n_{O_2},$$

where $k^* = \frac{\langle k_e n_e \rangle_{rf}}{\langle n_e \rangle_{rf}}$



a) b)

Fig. 2: a) Phase Resolved Optical Emission Spectroscopy image for Ar emission at 750 nm – one of three lines used in ERA for radial and axial determination of atomic oxygen; b) Electron temperature and atomic oxygen density in the ROI in the red rectangle [4].

SUMMARY

- Plasma species are very sensitive to parameters changes.
- Many existing diagnostic techniques, such as Optical Emission Spectroscopy can capture their responses.
- However, capturing temporal and spatial evolution in real-time generates lots of data.
- Good data analysis techniques are thus required to make use of this information for real-time feedback control mechanisms in industrial processing.

References

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