

SmartPIM Application Note No. 1 Plasma Impedance

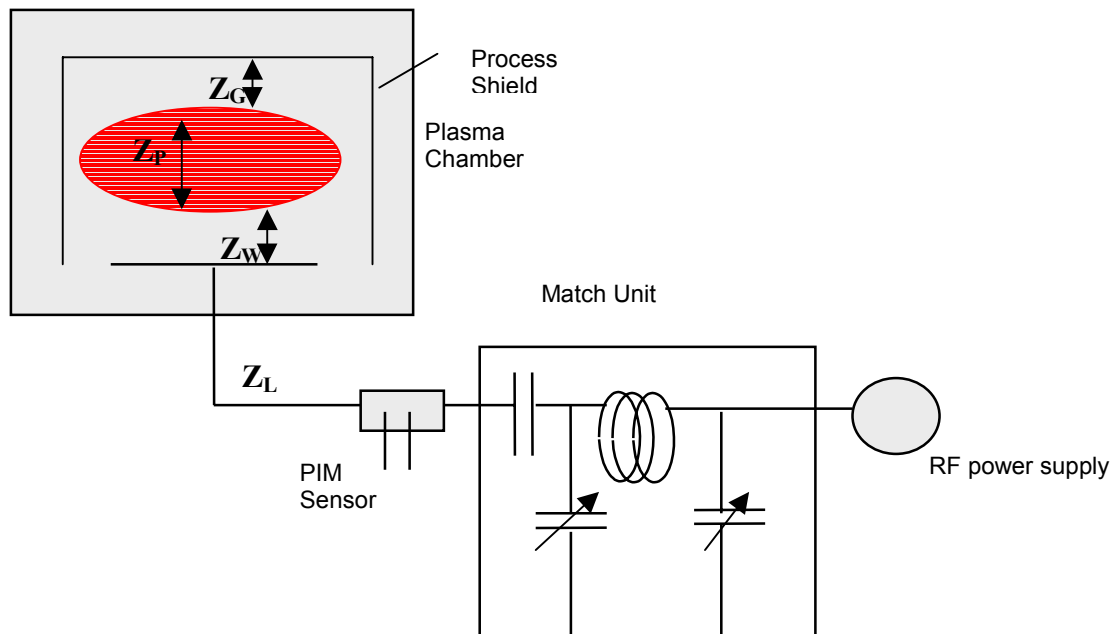
On most plasma processing systems, RF power to the chamber is measured only at the output of the power supply. It is assumed that this power is close to the power absorbed by the plasma. However, in most cases this is not true, since power is absorbed by the match unit itself, by the power lines and also by stray impedances along the power transfer path. Ideally, the power should be measured after the match. Furthermore, since the plasma is a non-linear load, harmonics of the fundamental are generated in the post match line. The ideal RF sensor should be capable of measuring these harmonics, since they contain fundamental information about plasma properties.

The power absorbed by the plasma is actually a product of the Voltage (V), the Current (I) and the cosine of the phase angle ϕ between these vectors, i.e.

$$\text{Power} = \text{Voltage} \times \text{Current} \times \text{Cos } \phi$$

It is far more useful to know the value of each of these components than to just know what the power is, since all three may change and still indicate the same power. Any process change will be indicated by a change in Voltage, Current, Phase or a combination thereof.

The Scientific Systems SmartPIM sensor measures 15 parameters - V, I, ϕ at the fundamental plus the next 4 harmonics.



The plasma chamber impedance is complex and is written as

$$Z = R + jX$$

where R is the real resistance, j is the unit complex number and X is the complex reactance. $X = X_L - X_C$, where X_L is the inductive reactance and X_C the capacitive reactance.

$X_L = \omega L$ and $X_C = 1/\omega C$, where $\omega = 2\pi f$ (f is the frequency of the signal), L is the load inductance and C is the load capacitance.

R and X can be derived from the measurement of V, I and ϕ at each harmonic using the relationships

$$\phi = \tan^{-1} (X/R) \text{ and } Z = V_0/I_0 = (R^2 + X^2)^{0.5}$$

The total plasma chamber impedance (i.e. the load seen by the match unit) is comprised of the plasma impedance Z_P , the plasma to ground impedance Z_G , the wafer and substrate impedance Z_W , and the RF line impedance Z_L .

Each of these impedances is complex, with resistive, inductive and capacitive components. Thus by accurately measuring the RF components with the SmartPIM sensor, changes in the load impedance can be accurately monitored. Any change in plasma, wall or wafer conditions results in a change in measured impedance, revealing information about the plasma process.

The plasma impedance is a function of
gas pressure, gas type, rf power

The plasma to ground impedance is a function of
wall conditions (ie polymer coating etc.), gas pressure, rf power, rf grounding

The wafer and substrate impedance is a function of
wafer placement, wafer type and film conditions, gas pressure, substrate power coupling

The rf line impedance is a function of
line length, line condition (kinks, bends, etc.)

Measuring the plasma chamber impedance can thus be used as a diagnostic for applications such as

- **Power levelling** - Plasma processes are a function of plasma power not RF generator power output. SmartPIM can be used to control plasma power.
- **Etch End-point Detection** - a plasma density change at endpoint results in a sheath impedance change, detected by the PIM sensor.
- **Chamber Clean End-point** - Polymer removal from plasma chamber walls results in a chamber impedance change, detected by the PIM sensor.
- **Plasma Repeatability / Chamber Matching** - any process changes in a plasma chamber or from chamber to chamber are detected by the PIM sensor. RF impedance fingerprints reduce downtime.
- **RF Ground Fault Detection** - problems associated with poor grounding or consumable part PM's can be diagnosed quickly.
- **RF Bias Applications** - many wafer plasma processes are a strong function of wafer bias (etch, CVD, metal plasma deposition). SmartPIM can detect very small changes in wafer bias power / current. Changes in e-chuck coupling can be easily measured.

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