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Top-to-tail microwave plasma sources with extended operating conditions

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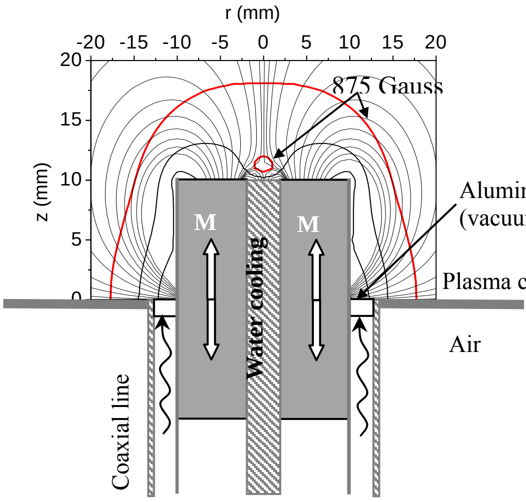
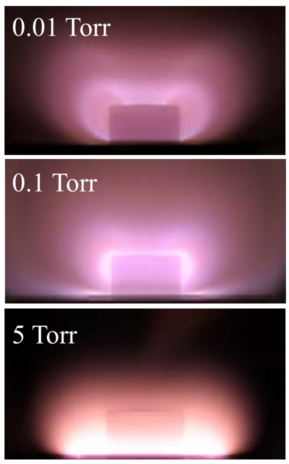
High performance microwave plasma sources in terms of density, energy efficiency, and flexibility of operating conditions (pressure, HF power) can be obtained by an adequate design of microwave applicator and its end configuration. The example described in this paper concerns a coaxial microwave applicator ended by top-to-tail magnetic configuration. Results clearly demonstrate that it is possible, at a given frequency (*i.e.* 2.45 GHz), to obtain efficiency greater than 80 % for operating windows, even without impedance matching. Auxiliary impedance matcher can be used for further adjustment of impedance in order to ensure an energy efficiency of the plasma source close to 100 % over wide pressure range.

The microwave plasma sources described here are derived from multi-dipolar [1,2] and matrix plasma [3] concepts, where individual plasma sources are used together to achieve uniform plasmas via their distribution over two-dimensional (planar sources) or tri-dimensional (volume plasma) networks. Each kind of elementary source operates in distinct pressure ranges, namely from ~1 mTorr up to 10 mTorr in argon plasma for multi-dipolar and beyond 100 mTorr for matrix configuration. To overcome this limitation and, particularly, to cover the 10-100 mTorr pressure range, which is of great interest in some applications, a new plasma source has been designed (Fig. 1). Based on coaxial microwave applicator ended by top-to-tail magnetic configuration, this kind of source allows highly extended operating conditions in terms of pressure range (from less than 10^{-3} Torr up to few Torr) and microwave power (from ~1 W up to several hundred W). Indeed, the ECR (electron cyclotron resonance) absorption, particularly efficient at low pressure (p < 100 mTorr) thanks to the magnetic field, continuously transits to the collisional absorption becoming more and more efficient when pressure increases, i.e. when the effect of the magnetic field is annihilated by collisions.



a)

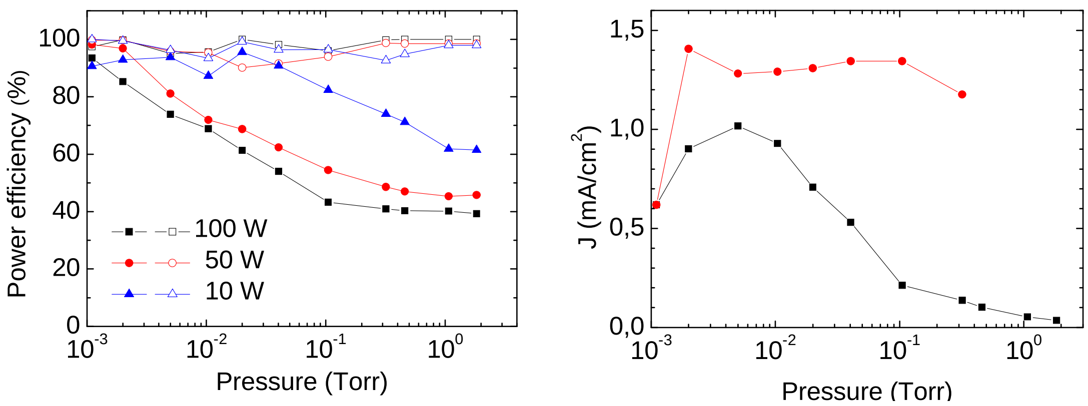


b)

Fig. 1 a) Elementary plasma source based on coaxial transmission line ended by top-to-tail magnetic configuration; b) Pictures of argon plasma (30 W, 2.45 GHz) for three pressures.

The efficiency of HF plasma source obviously depends on the efficiency of the wave-electron coupling and on the power transfer from the generator to the plasma. It is therefore not only necessary to avoid any losses along the whole transfer line, but also to ensure perfect impedance adaptation between the microwave generator and the plasma. Knowing that the plasma impedance can vary from one set of parameters (gas, pressure, plasma density) to the other, the wave-plasma coupling is effective only to a certain operating window corresponding to an impedance matching between the standard impedance of the transmission line (50 Ω) and the plasma impedance (≠ 50 Ω). In order to extend the operating window, an auxiliary impedance matcher can be used for fine adjustment. This will ensure an energy efficiency of the plasma source close to 100 % over a wide pressure and power range.

The microwave applicators are based on coaxial transmission lines λ/4 of length serving as impedance transformers between the standard transmission line and the plasma, and, for the design chosen as example, effective coupling is ensured in the low-pressure, low-power range. Figure 2 illustrates the transmitted power efficiency as a function of argon pressure, for three incident power values. For instance, at 10 W of incident power, the applicator is able to transmit more than 80% of it over up to 2 decades of pressure, from 10^{-3} Torr up to 10^{-1} Torr. On the contrary, for higher power, a good transmission efficiency is only ensured over a narrow pressure range, but the use of an impedance matcher improves the transmission up to almost 100% thus rendering the plasma source effective at any required pressure (up to few Torr) for a given application.



a) b)

Fig. 2 a) Transmitted power efficiency as a function of pressure for three incident power values P_i = 10, 50 and 100 W, with (empty symbols) and without (full symbols) impedance matching; b) Current density collected at 6 cm from the reactor wall as a function of pressure, when 100 W are fed in the plasma source, with (circles) and without (squares) impedance matching.

The plasma performance is shown in Fig.2b in terms of current density collected on 100 mm in diameter surface negatively biased (-20 V) and placed at 6 cm from the reactor wall. Results show that, when impedance is matched, one elementary plasma source (here at 100 W) can deliver 1.3 mA/cm^2 corresponding to a plasma density of the order of 5×10^{10} cm^{-3} (at 6 cm), and this over a wide pressure range. Compared to multi-dipolar plasmas only operating at low pressure ($p < 10$ mTorr) [1], the top-to-tail configuration generates higher plasma performance (1.3 mA/cm^2 using one source compared to 3 mA/cm^2 using 16 dipolar sources). The cumulative effect and the magnetic confinement between adjacent sources should lead to current densities much higher than 3 mA/cm^2. These measurements are currently underway.

References

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