41st European Physical Society Conference on Plasma Physics, Berlin, Germany, 23.- 27.6.2014

P2.139

Resonant rf network antennas for inductively-coupled plasma sources

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Introduction

Resonant rf networks are new plasma sources with numerous potential applications in plasma processing [1]. They consist of parallel arrangements of ***L***, ***C*** elementary meshes with resonant frequencies corresponding to the normal modes for the current/voltage distributions. At each resonant frequency, very high currents are generated in the antenna structure, hence it can be used as an inductively-coupled plasma source (ICP).

Experimental setup

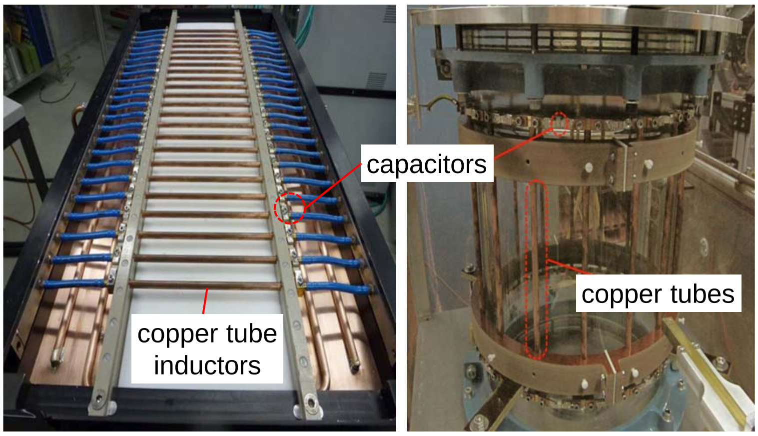

Fig. 1: Left: 23-leg planar resonant network before it is embedded in a dielectric and placed inside a vacuum chamber. Right: 16-leg cylindrical (birdcage) resonant antenna. The vacuum vessel is a glass cylinder closed at top and bottom by grounded metal plates.

The planar antenna in Figs. 1, 2 is for large area surface treatment; the cylindrical antenna is for volume plasma sources. The ***N*** parallel legs of each antenna are made of copper tubes which act as inductive elements ***L***. High Q capacitors ***C*** link the legs together and present a small inductance ***M***.

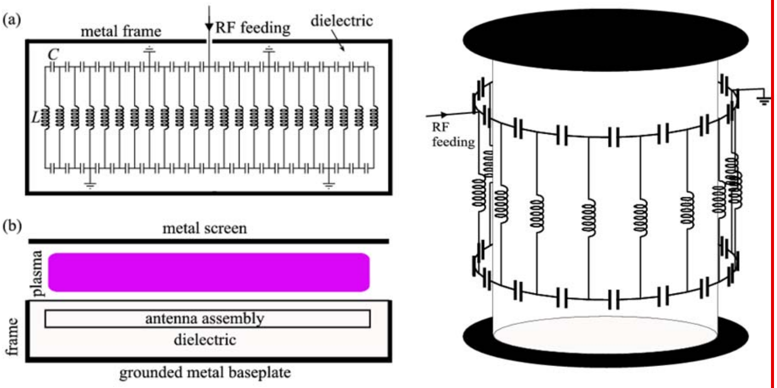

Fig 2. Left: Schematic of a 23-leg planar rf network antenna. (*a*) Top view; (*b*) Side view showing the metal screen used to confine the plasma.
Right: Schematic of a 16-leg cylindrical (birdcage) rf antenna, showing the points of rf feeding and grounding.

Solving Kirchhoff's equations with the boundary conditions of the planar structure gives ***m*** = [1,...,***N*-1**] normal modes [2]. Each mode has a specific current distribution (Fig. 3) and a resonance frequency

$$f_m = \frac{1}{2\pi}\left[C\left(M - 2L\sin^2\left\{\frac{m\pi}{2N}\right\}\right)\right]^{-1/2}.$$

Mutual impedances must be accounted for to reproduce the measured frequencies. The antenna behaves as a ***R***, ***L***, ***C*** parallel resonance circuit for each mode [2].

These plasmas show an *E-H* transition similar to ICP devices using solenoids or spiral coils [3]. Resonant rf networks have a real impedance near resonance which avoids strong voltages or currents in the rf power feedline, regardless of network size.

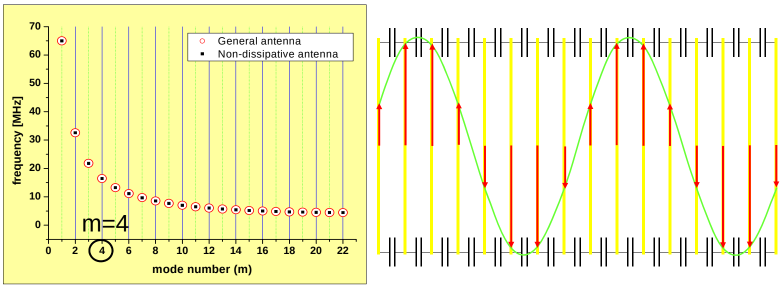

Fig. 3: Left: The mode frequencies of the planar antenna. The frequencies are not strongly altered by power dissipation in the antenna.
Right: Current distribution in the planar antenna legs for mode *m* = 4.

Protoypes of Helyssen antennas operating at 13.56 MHz have been tested up to 2 kW rf power and are currently under industrial pilot tests for barrier layer coatings in packaging, silicon thin film deposition for photovoltaic solar cells, and plasma sources for neutral beam heating.

Whistler-wave heated discharges using a planar antenna

Wave heated regimes are obtained with a static magnetic field perpendicular to the source plane above a given threshold. The measured propagating wave has the characteristics of whistler waves: The transverse magnetic field in Fig. 4 has a helical structure due to an elliptic polarization, with damped propagation away from the antenna. The high efficiency of planar resonant rf networks for launching whistler-wave heated discharges [4] means that plasma generation is not limited to a small skin-depth region, in contrast to ICP sources.

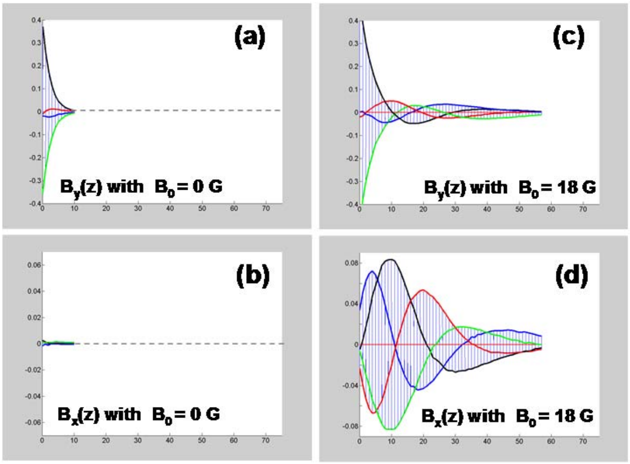

Fig. 4: Measured transverse field profile, $B_x(z), B_y(z)$ along the antenna axis for quarters of a period. (a), (b) without magnetic field (inductive coupling); (c), (d) with a 18 G static magnetic field.

Conclusions

These results show the proof of principle of a novel generic type of plasma source which overcomes many of the physical and technical limitations of conventional large-area capacitive and inductive plasma sources. The general principle of resonant networks for plasma sources opens up a rich field of study, and many new permutations of plasma source physics could evolve from this concept.

Acknowledgments

This work was supported by Swiss Commission for Technology and Innovation grants nos. 14693.1 PFIW-IW and 15082.1 PFIW-IW.

References

[1] Ph. Guittienne, S. Lecoultre, P. Fayet, J. Larrieu, A. A. Howling and Ch. Hollenstein, "*Resonant planar antenna as an inductive plasma source*", J. Appl. Phys. **111**, 083305 (2012)
[2] Ph. Guittienne, A. A. Howling, and Ch. Hollenstein, "*Analysis of resonant planar dissipative network antennas for rf inductively coupled plasma sources*", Pl. Sources Sci. Technol. **23**, 015006 (2014)
[3] Ch. Hollenstein, Ph. Guittienne and A. A. Howling, "*Resonant rf network antennas for large-area and large-volume inductively coupled plasma sources*", Plasma Sources Sci. Technol. **22**, 055021 (2013)
[4] Ph. Guittienne, A. A. Howling and Ch. Hollenstein, "*Generation of whistler-wave heated discharges with planar resonant rf networks*", Phys. Rev. Lett. **111**, 125005 (2013)