Topic number: 5

Inductive plasmas in Cl_2/Ar : Comparison of hybrid model results with experimental measurements

J.P.Booth[(*)], E.Despiau-Pujo, P.Chabert, R.Sarot
L. Gatilova[1] and S. Bouchoule[1]

Laboratoire de Physique des Plasmas
CNRS UMR 7648, Ecole Polytechnique, 91128 Palaiseau, France
1 Laboratoire de Photonique at Nanostructures,
CNRS UPR 20, 91460 Marcoussis, France

[(*)] **jean-paul.booth@lpp.polytechnique.fr**

Introduction

Inductively-coupled chlorine-based plasmas (often also containing Ar, HBr and O_2) are widely used in the microelectronics industry for the selective and anisotropic etching of nanometer-scale features in silicon thin films. They are also currently being developed for the etching of InP for the fabrication of photonic devices such as diode lasers and receivers for optical communications applications. We are making systematic measurements of internal plasma parameters. In parallel we are developing a hybrid simulation code based on the HPEM (Hybrid Equipment Plasma Model) of Mark Kushner. We will present comparisons of the measured and simulated values of the electron densities and temperatures as a function of RF power, pressure and gas composition. This comparison will be used to test and improve the simulation code. The aim is to reliably predict the plasma behaviour as a function of these parameters, and for arbitrary reactor geometries.

Experimental

The cylindrical reactor (height 15 cm, diameter 36 cm) operates in the pressure range 0.5-50 mTorr, and is excited by a flat spiral antenna though a flat dielectric window on the top. The electron density was measured with a microwave hairpin resonator[1]and compared to the results obtained with a Langmuir probe, which also gives measurements of the electron temperature. Both probes are located at a radial position of 17.5 cm.

Simulation

A 2-dimensional axi-symmetric fluid model is used. The species considered are Ar, Cl_2, Cl, Ar+, Cl_2+, Cl+, Cl-. Electrons, ions and neutral species are considered as three distinct fluids. The conservation equations for mass, momentum and energy are resolved for all species. In the gas phase the processes considered are ionisation, attachment, dissociation, detachment, excitation, charge exchange and ion-ion recombination. At the surfaces we consider ion neutralisation and recombination of Cl radicals to form Cl_2 with a coefficient of $\gamma_{rec}(Cl)= 0.03$. We assume a power coupling efficiency of 75% of the nominal RF power. An example of the electron density distribution profile at 1 mTorr 400W is shown in Fig 1.

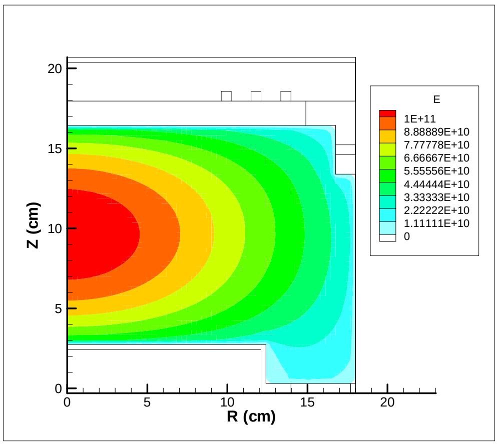

Fig 1. simulated electon density profile in a 1 mTorr 400W pure Cl_2 plasma.

Results

Fig 2 shows the variation of the electron density with the gas pressure in a pure Cl_2 discharge at 400W nominal RF power. The electron density decreases with Cl_2 pressure, as predicted by simple global models[2], due to the increased electron power loss due to elastic collisions. The electron density obtained with the Langmuir probe (calculated from the probe current with the probe potential equal to the plasma potential) shows a very comparable trend, but is systematically lower by 20-30 %. This difference can be attributed to the simplistic probe theory, which neglects any perturbation of the plasma by the probe.

The simulated plasma density (at the probe position) is also shown in Fig 2, and gives excellent quantitative agreement. The simulated electron density decreases with gas pressure, but at a rather steeper rate than was observed experimentally. This could be explained in a number of ways, including: a too high value of γ_{rec}(Cl)or neglect of it's spatial variation, variation of the power coupling efficiency with pressure.

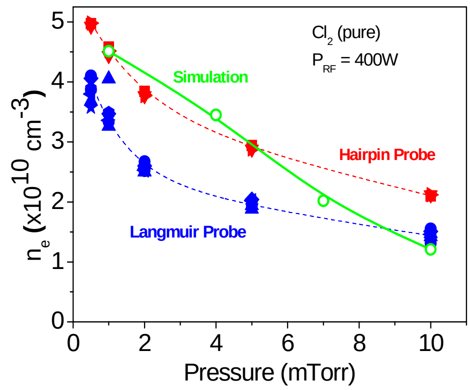

Fig 2 Variation of the electron density with gas pressure in a pure Cl2 dicharge at 400 W.

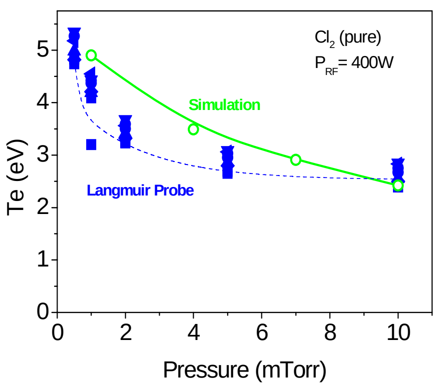

Fig 3 Variation of the electron Temperature with gas pressure in a pure Cl2 dicharge at 400 W.

The variation of the electron temperature is sjhown in Fig. 3. As expected, the electron temperature decreases as the pressure is increased, again due to to electron power loss through inelastic collisions. The simulation results are again in reasonable agreement with the experimental results.

The variation of the electron density and temperature with has composition in Ar/Cl_2 mixtures is shon in Figs 4 and 5. The electron density is highest in pure Ar, and decreases monotonically as the Cl_2 fraction is increased. This trend is also found in the simulation results, albeit with a lower slope. The electron temperature is observed to decrease slightly on transitionining from Ar to Cl_2.

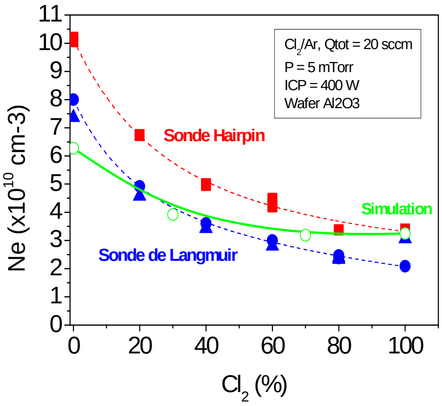

Fig 4 Variation of the electron density with gas composition in an Ar/ Cl_2 discharge at 400 W.

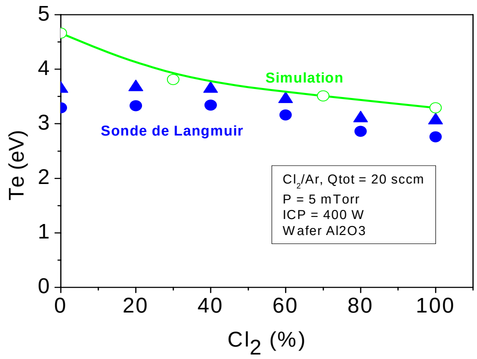

Fig 5 Variation of the electron temperature with gas composition in an Ar/ Cl_2 discharge at 400 W.

Figs 6 and 7 show the effect of RF power in a 80% Cl_2/20% Ar plasma at 5 mTorr.
The electron density increases linearly, as expected from global models, and is well reproduced by the simulations. The electron temperature increases only slightly as the RF power is increased.

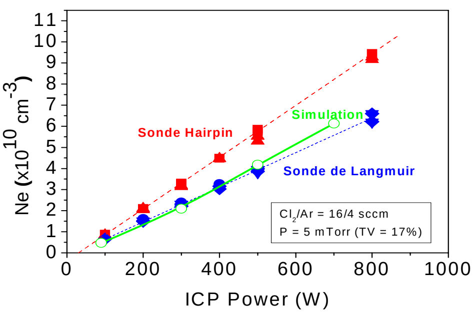

Fig 6 Variation of the electron density as a function of RF power in an 20%Ar/ 80% Cl_2 discharge at 400 W.

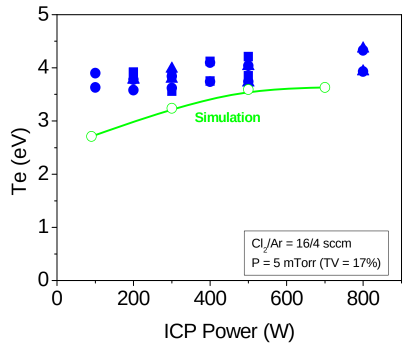

Fig 7 Variation of the electron temperature as a function of RF power in an 20%Ar/ 80% Cl_2 discharge at 400 W.

Conclusion and Perspectives

The electron density and temperature were measured in pure Cl_2 and Cl_2/Ar mixtures as a function of pressure, RF power and gas composition. Langmuir probe measurements of n_e follow the microwave hairpin resonator results, but were systematically 20-30% lower. The fluid simulation results are in good quantitative agreement, although they show slightly different quantitative trends with gas pressure and composition. We will attempt to reduce this difference by modifying the model in various ways, including full Boltzmann treatment of the electrons and ions.

In future work we will measure the Cl_2 dissociation fraction by UV absorption [3], and we will use two-photon laser induced fluorescence (TALIF) to measure the Cl atom number densities in the plasma.

References

1. Piejak, R.B., J. Al-Kuzee, and N.S. Braithwaite, *Hairpin resonator probe measurements in RF plasmas.* Plasma Sources Science & Technology, 2005. **14**(4): p. 734-743.
2. Lee, C. and M.A. Lieberman, *Global-Model of Ar, O-2, Cl-2, and Ar/O-2 High-Density Plasma Discharges.* Journal of Vacuum Science & Technology a-Vacuum Surfaces and Films, 1995. **13**(2): p. 368-380.
3. Neuilly, F., J.P. Booth, and L. Vallier, *Chlorine dissociation fraction in an inductively coupled plasma measured by ultraviolet absorption spectroscopy.* Journal of Vacuum Science & Technology a-Vacuum Surfaces and Films, 2002. **20**(1): p. 225-229.