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LLNL Large-Area Inductively Coupled Plasma (ICP) Source: Experiments.

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We describe initial experiments with a large (76-cm diameter) plasma source chamber to explore the problems associated with large-area inductively coupled plasma (ICP) sources to produce high density plasmas useful for processing 400-mm semiconductor wafers. Our experiments typically use a 640-mm diameter planar ICP coil driven at 13.56 MHz. Plasma and system data are taken in Ar and N_2 over the pressure range 3-50 mtorr. RF. inductive power was run up to 2000W, but typically data were taken over the range 100-1000W. Diagnostics include optical emission spectroscopy, Langmuir probes, and B-dot probes as well as electrical circuit measurements. The B-dot and E-M measurements are compared with models based on commercial E-M codes. Initial indications are that uniform plasmas suitable for 400-mm processing are attainable.

The recent development of high density ($n_{ion} = 10^{10}$-10^{12} cm^{-3}) plasma sources[1] (ECR, ICP, Helicon, Helical Resonator), has had a major impact on the semiconductor tool industry as these new sources provide many advantages for etch tools in terms of etch rate, directionality, selectivity, uniformity, cost of ownership, etc.. The new generation of tools based on these source developments should enable the push towards 0.35 to 0.25 micron semiconductor technology.

The semiconductor industry has also historically moved toward the direction of larger wafers. The SIA Roadmap[2] now points beyond the present 200-mm wafer to the introduction of 300-mm or 400-mm wafers in the near future. We are exploring the techniques to extend high density tools to this larger area regime. Such large area plasma tools should be useful not only for semiconductor processing, but also for flat panel display (FPD) processing.

To explore the technology of large area plasmas we have constructed an inductively coupled plasma device and have carried out an initial set of measurements to characterize this source. Our goals are to develop a plasma source for potential 300 mm to 400-mm wafer fabrication or for FPD applications. We focus on the ICP device because of its inherent simplicity and efficiency [3 [4] [5] and because of its success in the industry for 200 mm production [6]. Our initial development phase has focused on Ar and N_2 plasmas, but we are now setting up to run Cl_2. We coordinate our experimental efforts with the Livermore plasma process modeling group, in particular developing a synergy between our experimental results and the INDUCT 94 code to

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develop the predictive capability of the code as described in the accompanying manuscript [7].

A schematic diagram of our source is shown in Figure 1. A circular inductive coil, typically 640-mm diameter and 4 turns, couples 13.56 MHz RF electromagnetic energy from a source and matchbox to the plasma through a 51 or 63-mm thick dielectric window. The unit is capable of 5000 watts RF power , but we typically run between 100 to 1200 watts. The neutral pressure (Ar or N_2) was controlled at by a MFC/ turbopump combination over a typical pressure regime of 3- to 50- mtorr.

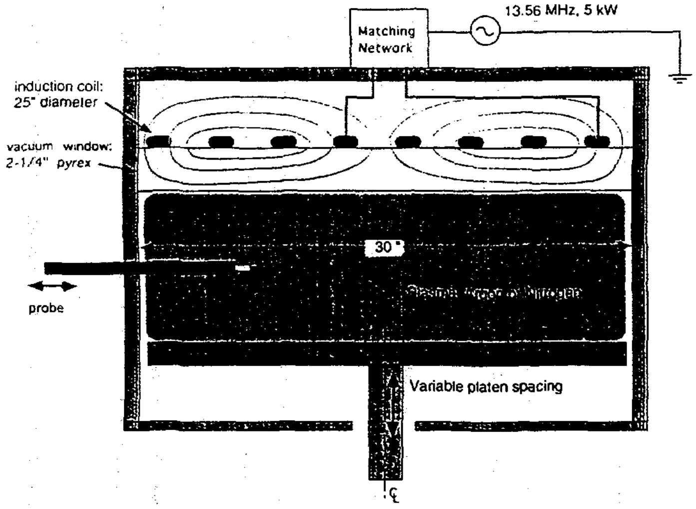
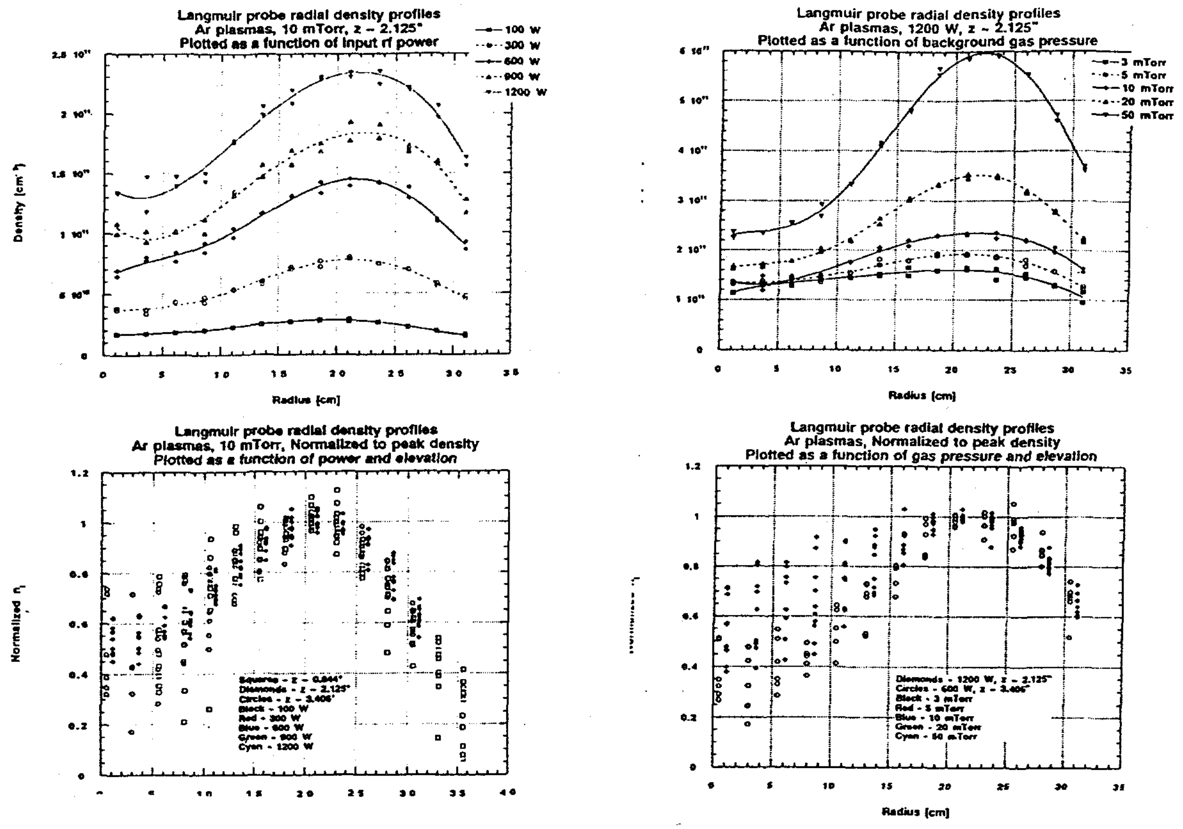


Figure 1. Schematic diagram of the Large Area ICP source.

Our initial diagnostics include several Langmuir probes to measure plasma parameters as well as B-dot probes to measure electromagnetic coupling. These are swept radially, as shown schematically in Fig 1, for a succession of elevations . We also perform electrical circuit measurements and have initial results on optical emission spectroscopy.

Langmuir probe measurements in argon are shown in Fig. 2 The density profiles are plotted as a function of both input RF power and background gas pressure. Normalized ion density profiles are shown at different elevations within the plasma chamber as functions of these same parameters. Electron density profiles, temperature profiles and plasma potential profiles are also obtained.

For argon the plasma density increases as the input RF power is raised , but the shape of the profile is unaffected by the RF power level (except perhaps at the lowest powers). The density profiles are not peaked on axis, due to the presence of localized heating under the RF coils and the mean free path in Ar at 10 mtorr, which is short enough to limit the ability of diffusion to flatten the profiles. The plasma density also increases as the background gas pressure is raised. In addition raising the background gas pressure increases the off axis density faster than the central density, thereby making the density profile more hollow -- a direct result of the decrease in the mean free path with increasing pressure.



Langmuir probe radial density profiles
Ar plasmas, 10 mTorr, z ~ 2.125"
Plotted as a function of input rf power

Langmuir probe radial density profiles
Ar plasmas, 1200 W, z ~ 2.125"
Plotted as a function of background gas pressure

Langmuir probe radial density profiles
Ar plasmas, 10 mTorr, Normalized to peak density
Plotted as a function of power and elevation

Langmuir probe radial density profiles
Ar plasmas, Normalized to peak density
Plotted as a function of gas pressure and elevation

Fig 2. Langmuir probe density data for Ar plasma

The Langmuir probe results for N_2 are shown in Figure 3. As in Ar, the plasma density increases with power. But, in contrast to the Ar results, the shape of the profile is strongly affected by the RF power level. The density profiles are peaked on axis at the lowest RF powers and become peaked off axis at higher powers. The reason for this change in the shape of the density profile is believed to be due to the low value of the density in these plasmas (compared to argon), leading to a large skin depth and non-localized heating at low RF powers.

The plasma density for N_2 also increases as the background pressure is raised, which also increases the off axis density faster than the central density, making the profile more hollow. This is a direct result of the decrease in both the mean free path as the gas pressure is raised, which limits the ability of diffusion to flatten the profiles, and the skin depth of the plasma, which gives rise to localized heating.

The general behavior has been modeled with the INDUCT94 code as described in the accompanying paper[7], and the salient features of the argon plasma have been reproduced in the model.

The coil-plasma system has also been modeled with two commercial electromagnetic codes, Ansoft Eminence and Ansoft Maxwell, and the models compared with B-dot probe measurements and E-M Network measurements. A comparison of the network analyzer impedance measurement (with the plasma replaced by a conductive

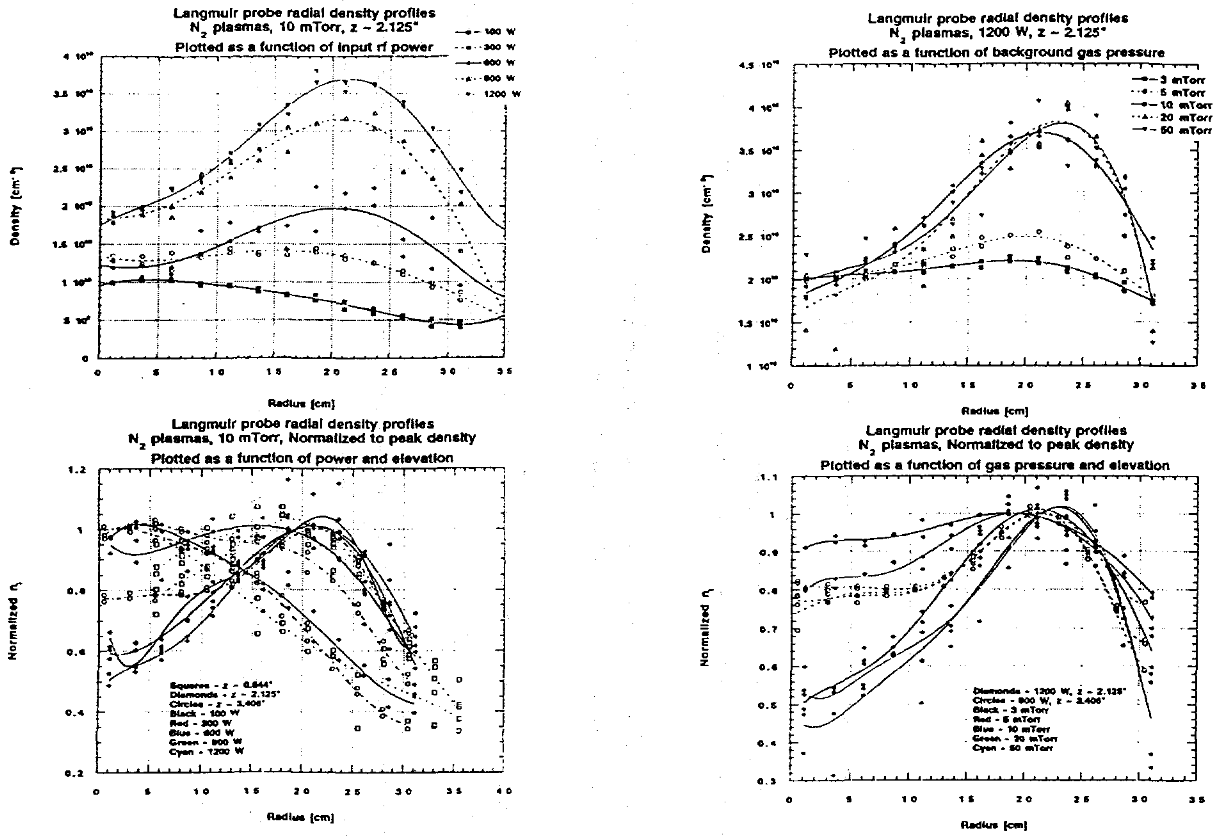


Fig 3. Nitrogen Langmuir probe density measurements

plate) with the prediction of the E-M model is shown in Fig 4. Note the agreement of the model for the observed resonance at 18.2 MHz, as well as for the behavior in the

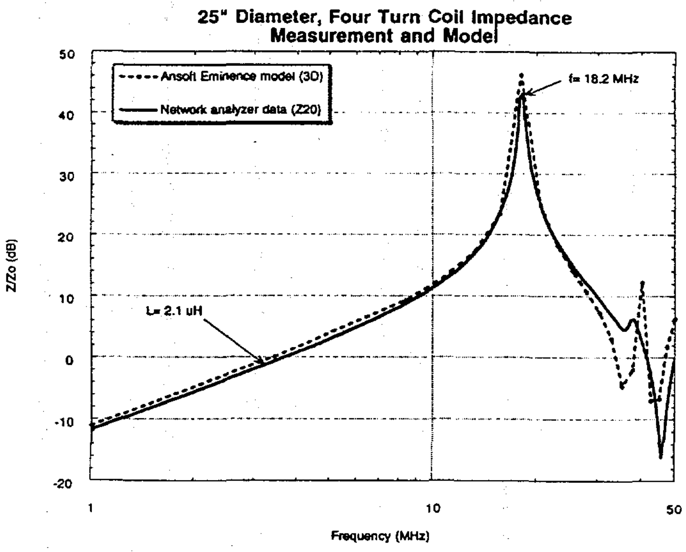


Fig 4. Network analyzer measurement compared to Ansoft Eminence Model.

inductive portion of the frequency sweep where the circuit actually operates (at 13.56 MHz).

A comparison of the measured vacuum B-dot fields with the modeled 2D fields is shown in Figure 5. The agreement is quite good, leading us to believe that our initial understanding of the EM behavior of the system is correct. Measurements of plasma B-dot fields from which we can extract values for the plasma conductivity will be shown in the poster portion of this work.

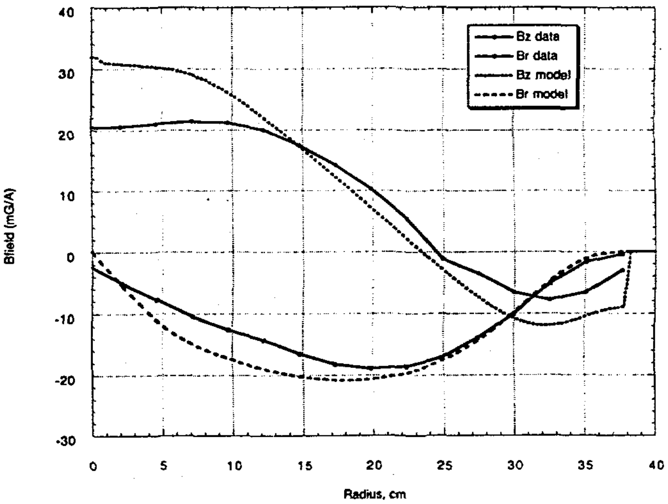


Figure 5 . B-dot data compared to Ansoft model

We have also developed a spatially resolved optical emission spectroscopy diagnostic. Light from the plasma is coupled to a 0.3 m visible-near UV spectrometer through an array of ten fiber optic light guides. The spectrometer is coupled to a two-dimensional CCD array so that one dimension displays wavelength and the other dimension indicates fiber position at the plasma. A example of this data is shown in Figure 6 for an SF_6 plasma.

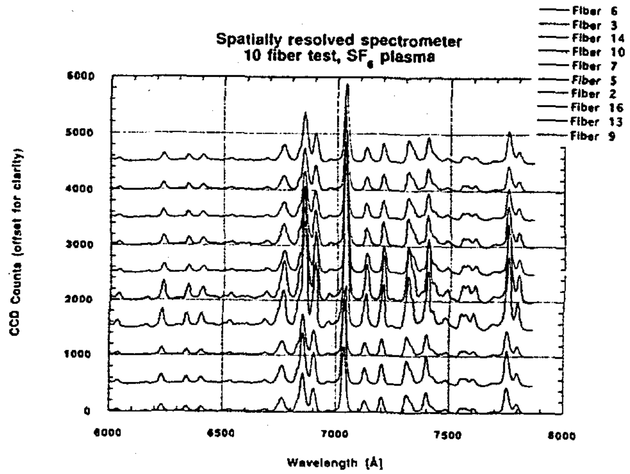


Figure 6. Spatially resolved optical emission spectra. SF6

Our initial experiments with large area ICP plasmas show that there are no technical showstoppers in creating a large plasma with this technique. For a reasonable range of operating conditions we are able to create plasmas of suitable uniformity to encourage this source geometry for large wafers and FPDs. Our experiments can be adequately modeled by the INDUCT94 techniques described in the accompanying manuscript.

We are now engaged in refinements to the initial experiment. We are exploring different coil and window geometries. We are also refining the diagnostic techniques, particularly the EM and optical emission measurements to provide more insight into the plasma processes.

Acknowledgments

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