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Transition from interpulse plasmas to afterglows in a pulsed microwave discharge

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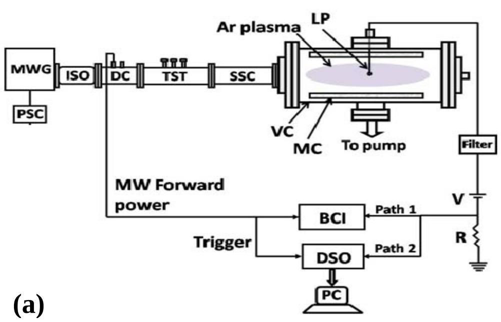
An experimental investigation of “interpulse” plasma and its transition to afterglow is reported as a function of microwave pulse duration (20 - 200 μs) at low pressure argon (0.2 – 2.0 mTorr). Interpulse plasmas are characterized by a quasi steady state period in electron density n_e (t) and a relatively slow decay time constant of the electron temperature T_e (t) as compared to afterglows where the plasma rapidly decays at the end of the pulse. The electron energy probability function (EEPF) indicates an increase in high energy electrons in interpulse plasmas just after the end of the pulse.

Pulsed plasmas can have interesting features in the power off phase. An afterglow plasma is characterized by the plasma reaching a steady state within the pulse and low electron temperature (T_e ~ 1-2 eV) [1]. Whereas there are situations where an “interpulse plasma” is created which is characterized by a temporally growing plasma even after the end of the pulse with a relatively high T_e (~ 6–10 eV) with slow exponential decay [2]. In this paper we investigate the transition from interpulse plasmas to afterglows in pulsed microwave (2.45 GHz) plasmas of peak power 3 – 10 kW as a function of pulse duration (20–200 μs). In particular we look at the role of high energy electrons in such a transition.

The experimental set-up is as shown in Fig. 1(a). The microwave pulses (peak power 3.2 kW and pulse repetition period 2500 μs) generated from a magnetron (MWG) are guided to a vacuum chamber (VC, d = 20 cm, l = 50 cm) via WR340 waveguide. A 12-pole multicusp (MC, d = 12 cm, l = 25 cm) is used for plasma confinement in a minimum B-field configuration. A box-car integrator, BCI (Stanford Research Systems SRS250) is employed for time-resolved measurements (gate width 100 ns, averaging 1000). The plasma diagnostics are done using a planar Langmuir probe of diameter d = 4 mm and an electron energy analyzer EEA probe as shown in Fig. 1(b).



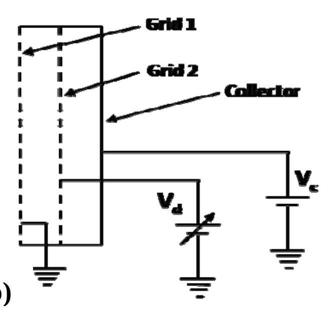


Figure 1 (a): Schematic of the experimental set-up: PSC, power supply and controller; MWG, microwave generator; ISO, magnetron oscillator; DC, directional coupler; TST, triple-stub tuner; SSC, straight section; VC, vacuum chamber; MC, multicusp; LP, Langmuir probe; BCI, box-car integrator; and DSO, digital oscilloscope, (b): Bias scheme of Electron Energy Analyzer EEA, which consists of two grids and a collector (spacing between each is 0.5 mm, diameter 3 mm).

Figure 2 (a) shows n_e (t) and T_e (t) profile at 20 μs pulse duration of microwaves. It shows that n_e increases to a peak value at the end of the pulse and is being maintained beyond the end of the pulse for about 60 μs (three times the pulse duration) in the power-off phase, followed by a slow decay. The T_e ~ 4.8 eV at the pulse end and then decays exponentially attaining 1 eV in 60 μs after the end of the pulse. Figure 2 (b) shows time evolution of n_e at a higher pulse duration of 100 μs which acquires a saturation value ~ 1.2 x 10^{11} cm^{-3} within the pulse and then decays off exponentially after the pulse ends – typical of an *afterglow* plasma. The T_e ~ 4.2 eV at the end of the pulse, decays exponentially and reaches 1 eV in 40 μs after the end of the pulse.

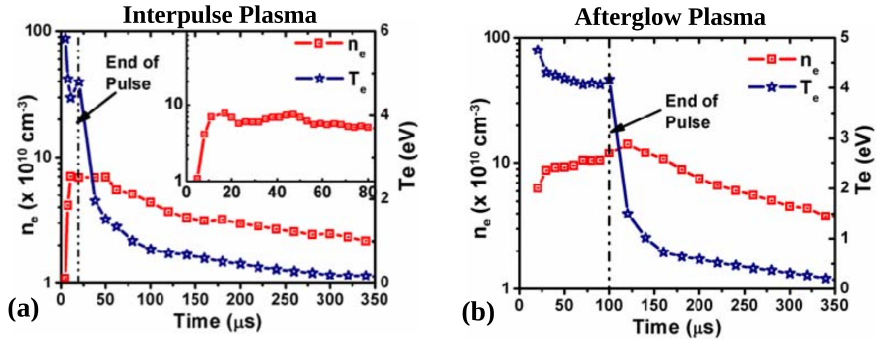


Figure 2: The n_e (t) and T_e (t) profile at (a) 20 μs pulse duration with an inset showing an expanded view of n_e (t) indicating interpulse plasma, and at (c) 100 μs indicating afterglow plasma.

Figure 3 (a) and (b) shows the EEPF profile at different time intervals after the end of the pulse, for pulse duration of 20 and 100 μs respectively. In interpulse plasma (Fig. 3 (a)), a drop in low energy electrons and an increase in high energy electrons is observed at t = 30 and 40 μs, just after the end of the pulse (also shown in the inset). After 40 μs, electrons of all energies begins to decrease. However, in afterglow (Fig. 3(b)) no such increase in high energy electron component is observed, instead electrons of all energies show continuous decay. A more clear representation is shown in Fig. 4, where Fig. 4 (a) and (b) shows temporal profile of (normalized) collector current I_{cn} of EEA at discriminator bias voltages V_d = 10 V and 90 V, respectively, with reference to end of the pulse (t = 0). At V_d = 90 V, I_{cn} (t) mostly consists of electrons with energy > 90 eV and hence Fig. 4 (b) gives information of high energy electrons population. It clearly confirms that decay rate of high energy electrons is slower at low pulse duration and plays an important role in sustaining interpulse plasma state.

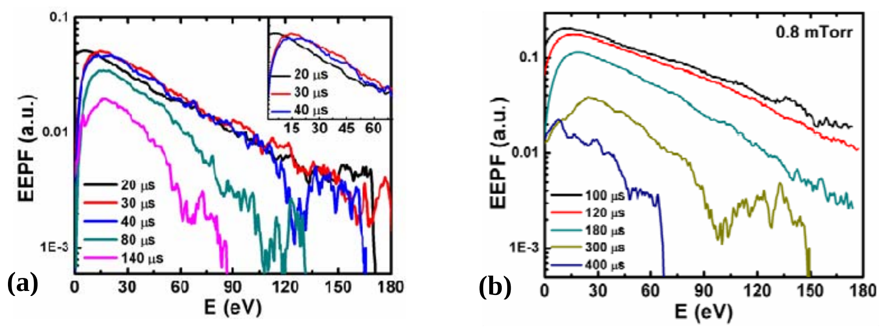


Figure 3: EEPF evolution after the end of the pulse for pulse duration (a) 20 μs, and (b) 100 μs.

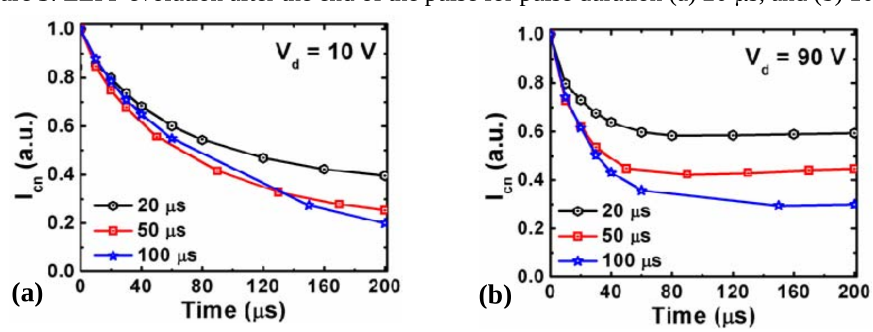


Figure 4: Temporal variation of EEA collector current after the end of the pulse (taken as t = 0), as a function of microwave pulse duration, by keeping discriminator voltage at (a) 10V and, (b) 90V.

References

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[2] S. Bhattacharjee, I. Dey, A. Sen, and H. Amemiya, J. Appl. Phys. **101** (2007), 113311.