UCLA experiments on high power microwave – plasma interaction

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Large Plasma Device (LAPD)

Machine parameters

<table>
<thead>
<tr>
<th>chamber size</th>
<th>1 m diameter 20.7 m long</th>
<th>discharge plasma parameters</th>
<th>n_e ~ 3×10^{12} cm^{-3}</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_0</td>
<td>up to 3.5 kG, variable profile</td>
<td></td>
<td>T_e ~ 6 eV, T_i ~ 1 eV</td>
</tr>
<tr>
<td>Fill pressure</td>
<td>~ 5×10^{-5} Torr</td>
<td>afterglow plasma parameters</td>
<td>n_e ~ 5×10^{11} cm^{-3}</td>
</tr>
<tr>
<td>plasma production</td>
<td>DC discharge, 1 Hz repetition</td>
<td></td>
<td>T_e ~ 0.5 eV, T_i ~ 0.1 eV</td>
</tr>
</tbody>
</table>

Plasma Column: L = 21 m, D = 60 cm

UCLA experiments
Experimental schematic

- Cathode anode
- Vacuum sealed waveguide
- Horn antenna
- Density gradient
- Microwave source
- Plasma column
- Probes

Dimensions:
- 1000 cm
- 1800 cm
- 60 cm
- 100 cm

Not shown to scale.
Pulsed microwave source

- Upgraded microwave source with the addition of pulse modulation capability:
  - HV pulsed modulator: 10 kV / 100 Amp
  - Microwave pulse length = 0.5 ~ 2 us continuously variable
  - Max modulation frequency = 200 kHz
  - Peak output power = 250 kW
  - Microwave Frequency = 8.5 ~ 9.5 GHz

Surplus radar module
High power vacuum window
High power isolator
Pulsed HV supply with tunable rep-rate
To LAPD
Measured microwave propagation

**O-mode**

- Measured microwave intensity
- Measured plasma density

**X-mode**

- Measured microwave intensity
- Measured plasma density

Graphs showing microwave intensity and plasma density across different distances.
Fast electrons generated by microwaves

- Fast electrons (~100 eV) are generated by the high power microwave pulses, which radiate whistler waves and lower hybrid waves.
Shear Alfvén wave generation by microwave power modulation (Virtual Antenna)

- When the microwave pulses are modulated at a frequency below $f_{ci}$ (ion cyclotron frequency), an Alfvén wave at this frequency is detected.
Virtual antenna - Alfven Wave pattern

- Radiation pattern of the “Virtual antenna” shows high similarity to that of a physical antenna.

Wave launched by “virtual antenna”
- Microwave horn outside plasma

Alfven Wave launched by a small disk antenna

Virtual antenna - Alfven Wave pattern

- Different wave patterns can be selected by controlling the plasma density gradient.

The Alfven wave frequency is controlled by changing the microwave pulse modulation frequency.
Verification of dispersion relation

- The dispersion relation of shear Alfvén wave has been verified with the wave launched by the virtual antenna.

![Graph showing the dispersion relation](image)
Microwave power dependence

X-mode

O-mode
Planned experiments

1) Plasma response (heating, cavity formation, fast electron distribution function, plasma flow, etc.) at various incident microwave power levels, benchmark linear/nonlinear transition

2) Oblique incidence, O-X conversion;
   high power microwave trapping by a “plasma ring”
Planned experiments ...

3) Whistler/lower-hybrid waves
4) Langmuir wave / Bernstein wave studies, which require high frequency micro-probes

High frequency EB probe