Summary of Instabilities in Low-Pressure Inductive Discharges

SFR Workshop & Review
November 14, 2002
Berkeley, CA
A. M. Marakhtanov M. A. Lieberman, and A. J. Lichtenberg (UC Berkeley), P. Chabert (Ecole Polytechnique), and M. Tuszewski (Los Alamos National Laboratory)

Instabilities in Processing Plasmas

Instability range in SF$_6$ plasma

Instability range in Ar/SF$_6$ (1:1) plasma

Plasma instabilities have been observed in low pressure inductive discharges with electronegative gas feedstocks (O$_2$, SF$_6$, etc)
Instabilities in SF₆ and Ar/SF₆ Plasma

Instability Frequency vs. Power

- SF₆
- Frequency of light (kHz)
- Power (W)
- Pressures: 10 mTorr, 20 mTorr, 40 mTorr, 50 mTorr, 60 mTorr, 70 mTorr, 80 mTorr, 90 mTorr, 100 mTorr

Instability Frequency vs. Chemical Composition

- Ar/SF₆ mixture: 90/10 %, 75/25 %, 50/50 %, 25/75 %, 10/90 %
- Frequency (kHz)
- Power (W)

Instability Frequency vs. Gas Pressure

- SF₆
- 650 W, 650 W fit, 750 W
- Frequency of light (kHz)
- Pressure (mTorr)

Instability Frequency vs. Gas Flow Rate

- Ar/SF₆ (1:1), 5 mTorr
- SF₆ flow rate: 2.2 sccm, 4.5 sccm, 7.1 sccm
- Frequency of light (kHz)
- Power (W)

11/14/2002
Ar/SF$_6$ Plasma Parameters vs. Instability

![Graphs showing variations in plasma parameters](image)

**Ar/SF$_6$ (1:1) 5 mTorr, 550 W**

**Ar/SF$_6$ (1:1) 5 mTorr, 350 W**
Theoretical Model and Instability Mechanism

Particle balance:

\[ \frac{dn_e}{dt} = n_e n_g K_{iz} + n_- n_g^* K_{det} - n_e n_g K_{att} - \Gamma_e \frac{A}{V} \]

\[ \frac{dn_-}{dt} = n_e n_g K_{att} - n_- n_g^* K_{det} - n_+ n_+ K_{rec} - \Gamma_\frac{A}{V} \]

Power balance:

\[ \frac{d}{dt} \left( \begin{array}{c} 3 \\ 2 \end{array} \right) \begin{pmatrix} n & T \\ e & e \end{pmatrix} = P_{abs} - P_{loss} \]

\[ \Gamma_+ = \Gamma_e + \Gamma_- \]

\[ n_+ = n_e + n_- \]

1-2: \( n_e \uparrow \) (fast), Cap. \( \Rightarrow \) Ind. \( n \uparrow \) (slow)

2-3: Inductive: \( n_e \downarrow \), \( n_- \uparrow \) (slow), \( P_{loss} \uparrow \)

3-4: \( n_e \downarrow \) (fast), Ind. \( \Rightarrow \) Cap., \( n_- \downarrow \) (slow)

4-1: Capacitive: \( n_- \downarrow \), \( n_e \uparrow \) (slow), \( P_{loss} \downarrow \)
Global model phase plane and time variations of charged particle densities, electron temperature and plasma potential for a 5 mTorr Ar/SF₆ (1:1) mixture at (a) 294 W and (b) 300 W. The system is tuned at \( n_e = 1 \times 10^7 \text{ cm}^{-3} \).
Effect of Capacitive Coupling on Instability

- Capacitive coupling and stable capacitive region reduced by Faraday shield
- Plasma instability continuously reduced by increase of the shielded area from 25 to 65%
- Plasma relaxation oscillation frequencies decrease with shielded area increase
- No instability observed for shielded area >65%

Ar/SF₆ (1:1) 5 mTorr
Effect of Capacitive Coupling on Instability.
Global Model Results

- Instability windows are narrower in the model than in the experiment
- Instability frequency decreases with the power increase as seen in the experiment
- No instability observed for shielded area >85%
Transition from Stable to Unstable Discharge

Chaotic behavior of the plasma parameters has been observed in the transition from stable to unstable discharge.
Spatial Variations During Instability

- Spatial variations seen at higher pressures
- Instability decays more rapidly as pressure increases

Probe @ -50 V

Ar/SF₆ (1:1) 5 mTorr, 450 W

Ar/SF₆ (1:1) 40 mTorr, 200 W
2002 and 2003 Goals


Study new types of instabilities: (a) Propagating inductive (kHz), (b) Low frequency (Hz). Examine effects of chemical composition on the instability

Publications