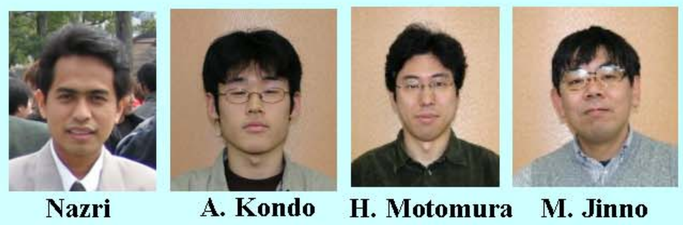
Mode Transition in Xenon ICP Discharge Lamp

Ahmad Nazri, Akira Kondo, Shuji Inui, Hideki Motomura, Masafumi Jinno

Dept. of Electrical and Electronic Engineering, Ehime University

(E-mail: *nazri@mayu.ee.ehime-u.ac.jp*)



Nazri A. Kondo H. Motomura M. Jinno

Introduction

Mercury-free
- safe for environment
- not influenced by ambient temperature

Electrode-less
- long lifetime
- no sputtering problem

Mercury-free Electrode-less Lamp
- used rare gas (xenon) as replacement to mercury
- used electrode-less discharge, ICP (ICP: Inductively Coupled Plasma)

What is ICP ?
- used electromagnetic induction law
- no electrode is needed
- high electron density can be obtained
- mostly applied in semiconductor devices processing
- two types of mode discharge exist i.e. E-mode (capacitively) and H-mode (inductively)

In this study

Basic characteristics of mode transition from E-to H-mode in xenon ICP discharge have been investigated !

Experimental Set-up

- 4-turn coil (copper tape, 0.1 mm x 4 mm) is wound at the middle of the lamp
- luminance was measured at the middle (gap between 2nd and 3rd turns) of the lamp
- RF power was gradually increased from lowest power that could start the discharge until mode transition occurred, and continued until input power saturated
- input power was decreased until the minimum power that could sustain the discharge

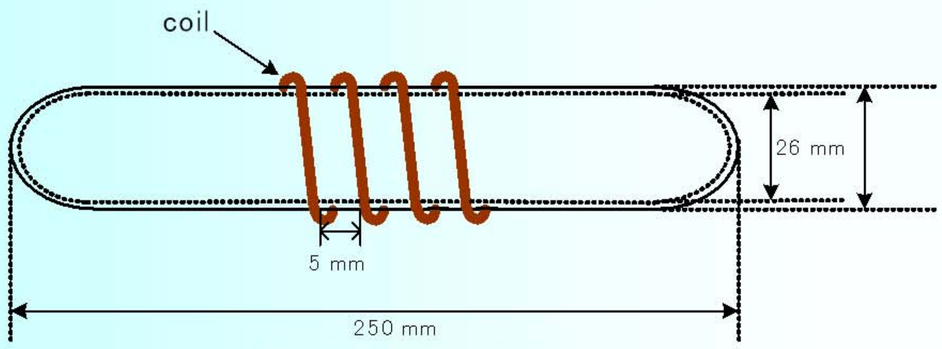
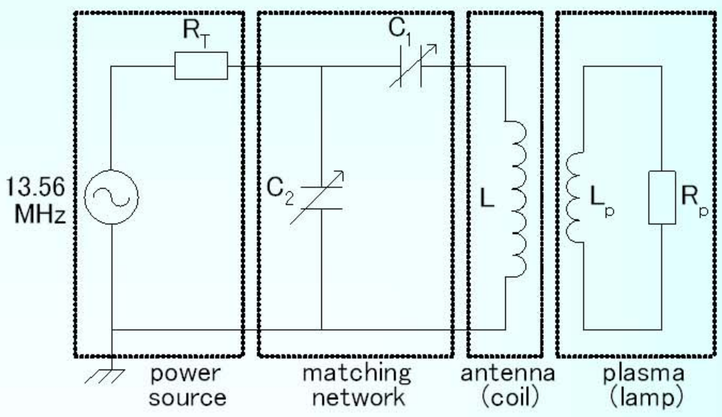


Fig. 1 Cylindrical discharge tube



R_T : Thevenin-equivalent source resistance
C_1 : variable capacitor
C_2 : variable capacitor
L : external coil inductance
L_p : internal plasma inductance
R_p : internal plasma resistance

Fig. 2 Equivalent circuit

Table 2 Gas pressures

Gas Type	Xenon						
Gas Pressure	1 Torr (133 Pa)	10 Torr (1.33 kPa)	30 Torr (3.99 kPa)	50 Torr (6.65 kPa)	70 Torr (9.31 kPa)	100 Torr (13.3 kPa)	150 Torr (9.95 kPa)

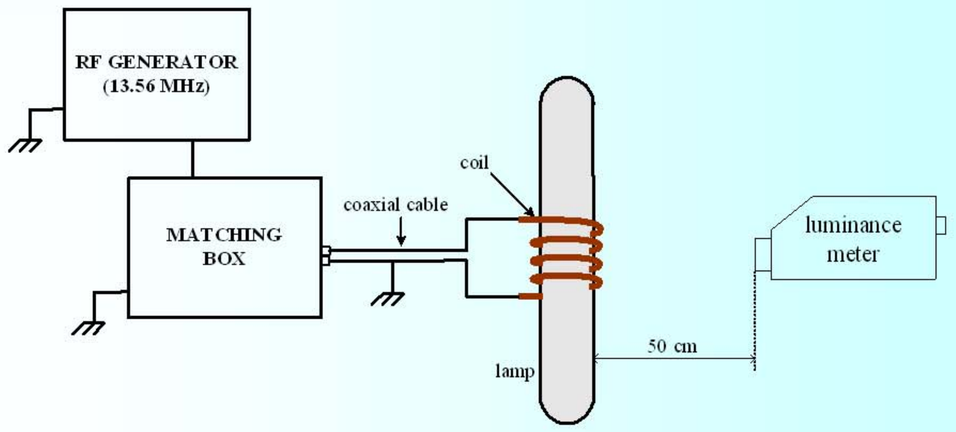


Fig.3 Connection diagram

Results and Discussion

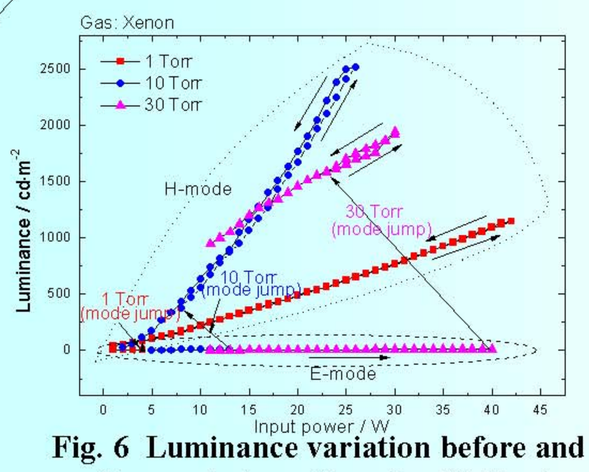


Fig. 6 Luminance variation before and after mode transition (1 − 30 Torr)

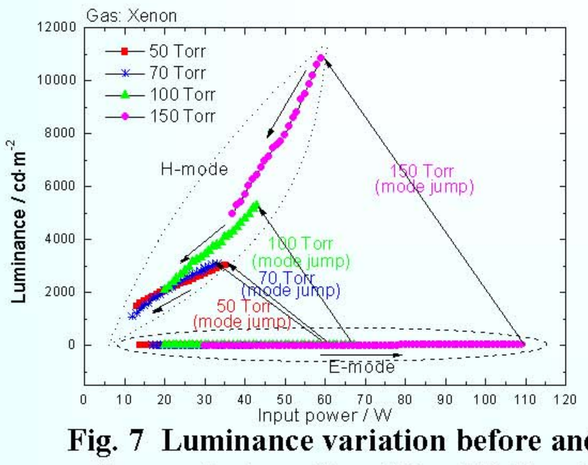


Fig. 7 Luminance variation before and after mode transition (50 − 150 Torr)

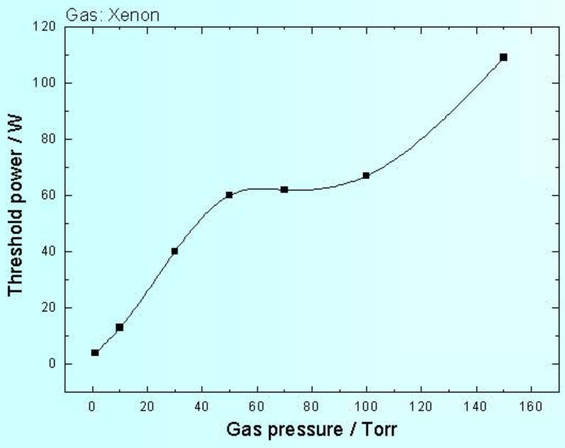


Fig. 8 Mode transition point

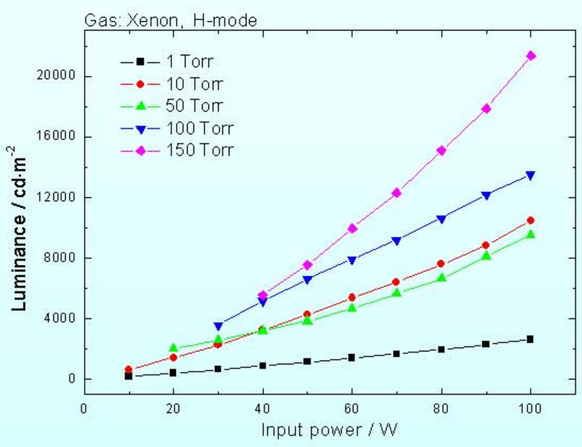


Fig. 9 Luminance at H-mode

gas pressure ↑ ⇒ power required for mode transition ↑

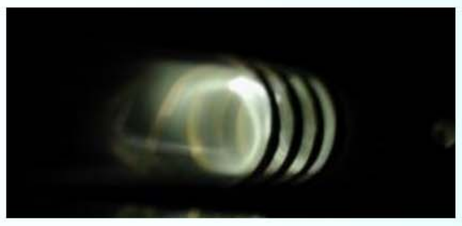


Fig. 4 Discharge images (E-mode, Xe 50 Torr)

Fig. 5 Discharge images (H-mode, Xe 50 Torr)

- at low RF power, discharge is sustained mostly by the electrostatic field due to potential difference across the coil (E-mode)
- when power is increased, inductive field becomes more important than electrostatic field, mode transition is produced in the discharge (H-mode)
- when xenon pressure is increased, power that was required for mode transition also increased
- from Boltzman equation, with gas pressure condition is $\nu > \omega$, when pressure is increased ν will also increase and the average power transfer will decrease

$$P_{ave} = \frac{e^2 E_p^2 \nu}{2m(\nu^2 + \omega^2)}$$

$$\nu = n\langle \sigma v_e \rangle \quad (\nu > \omega)$$

$$P = nkT$$

P_{ave} : power transfer
ν : collision frequency
ω : angular frequency
v_e : electron velocity
σ : collision cross section
k : Boltzman coefficient
n : gas density
P : gas pressure

Summary

	luminance	plasma length
E-mode	low	long
H-mode	high	short

Effect of gas pressure

High luminance can be obtained at high pressure, but at a same time high power is needed to transform the discharge into H-mode

Future works

Extending our study to a wider range of xenon pressure and obtaining detail plasma parameters