Optical emission technique for understanding the Spark gap Discharge and life time analysis

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Abstract - *This paper presents the Optical Emission Spectroscopy (OES) technique to study the Spark gap discharge in Argon, Nitrogen and helium gasses at 0-2 kg/cm² pressure range. The life time is also estimated for the gas ambiance for varying pressure conditions. Based on the life time profiles, the plasma temperature and electron density are determined by the intensity ratio of emission lines of excited atoms. The obtained results are in agreement over a wide electron density range 10^8-10^{15} cm^{-3}.*

Key Words: Spark gap, Breakdown, spectroscopy, plasma temperature, electron density.

1. INTRODUCTION

One of the most conventional high peak power switching device is the spark gap. The spark gap has multiple advantage to use as a switch in pulsed power circuit due to its simplicity, wide operating voltage and current range, high dv/dt. One of the major drawbacks with repetitive pulsed power spark gap is recovery of spark gap voltage. The lower pressure spark gap recover greater than their breakdown voltage of first pulse under certain condition, which is called "over recovery" [1, 2]. To understand the discharge properties the measurement of electron density and temperature is essential.

There are two major factors influences the insulation characteristics of gas switch. One is the rate of decrease in the gas temperature and the other is the vanishing of electron following the extinction of arc current, the volume between the two electrodes is filled with hot decaying plasma in which the degree of ionization is rapidly decreasing. But the metal hot gas remain for a relatively long time and is cooled by the heat flow to the surrounding ambient gas and the electrodes, the recovery characteristics are governed entirely on the gas temperature[3].

It is essential to understand the local temperature variation due to plasma formation during breakdown process and influence of various species formed due to constitution of the medium on the recovery voltage process has to be ascertained. Having known all this, in the present study, an attempt has been made to understand the mechanism of spark gap discharge under the influence of different gas discharge. The emission spectra, plasma temperature and electron density are also investigated.

2. EXPERIMENTAL SETUP

Figure 1 shows the experimental set up for the emission spectroscopy measurements with spark gap chamber. The supply voltage (0-230 V, AC) was stepped up using a transformer and fed to a voltage doublers circuit. The capacitor was charged through the voltage doublers circuit and discharged through the spark gap which was connected across the chamber.

An impulse generator consists of a capacitor that is charged to the required voltage and discharged through a circuit. The circuit parameters can be adjusted to give an impulse voltage of the desired shapes. An equivalent circuit of an Experimental setup is shown in Figure 2, where the capacitor C_G (10000pf) is charged from a DC source until the spark gap breaks down. The voltage is then impressed upon the object using a capacitor having capacitance C_L (1200pf). The wave shaping resistors, R_f (416Ω) and R_t (10kΩ), control the front and tail of the impulse voltage available across C_L, respectively. Overall, the wave shape is determined by the values of the generator capacitance (C_G), the load capacitance (C_L), and the wave control resistances, R_f and R_t. If the tail time, T_t, is sufficiently greater than the front time, T_f, and the total load capacitance, C_L, is less than 1/5 of the generator capacitance, C_G (i.e., stage capacitance/number of stages), then an approximation to the wave shape can be determined from

$$T_f = 3.2 R_f \frac{C_G C_L}{CG + CL} \quad (1)$$

$$T_t = 0.7 R_t (C_G + C_L) \quad (2)$$

The output voltage wave form can be defined accurately by

$$V_0(t) = \frac{V_c}{C_L R_f (\alpha - \beta)} \left(e^{-\alpha t} - e^{-\beta t} \right) \quad (3)$$

3. Analysis of Optical Emission Signal during Spark gap discharge process:

The Optical emission spectroscopy (OES) Technique is used to study the behavior of spark gap discharge with
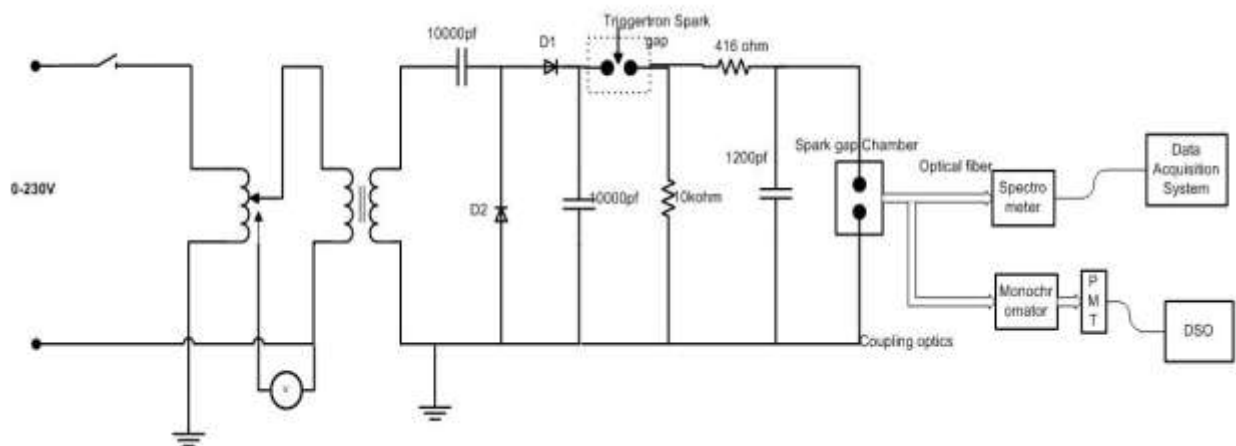
Figure-1: Experimental Setup

Nitrogen, Argon and Helium gasses from zero 2 kg/cm2 pressure range. An impulse voltage (double exponential pulse with a front time of 1.2us and tail time of 50us) is applied to the spark gap of which electrodes are of rogowsky profile type and thickness of 15mm having an inter electrode gap of 10mm. Applied voltage is measured using a $CuSo_4$ resistive divider having division ratio of 1800:1. Optical emission during spark gap discharge on different gasses is collected, using a fiber lens with a focal length 150mm and it is coupled to a spectrometer (Ocean optics, USB2000) using a multimode optical fiber with a core diameter of 400um.
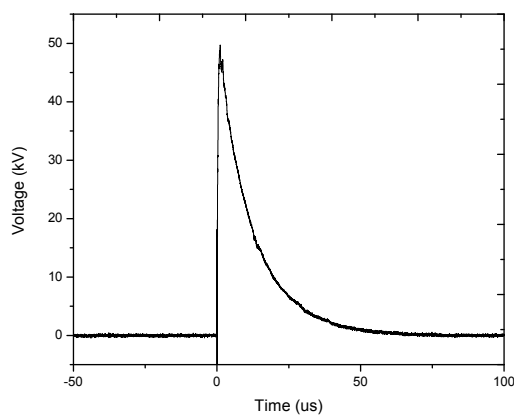

Figure-2: Voltage pulse applied to the spark gap

An attempt was made to estimate temporal distribution of plasma temperature from the life-time profile. Fig3, 4 and 5 shows the optical emission spectra of Argon, Nitrogen and Helium gas ambience at 2 kg/cm2 pressure.
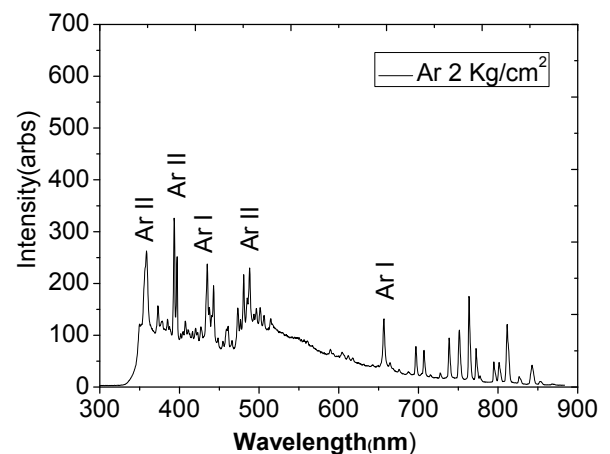

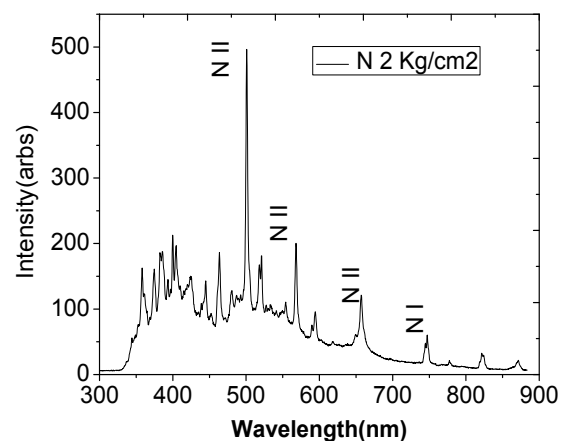**Figure-3**: Optical emission spectra obtained during the spark gap discharge in the Argon ambience at 2kg/cm^2

Figure-4: Optical emission spectra obtained during the spark gap discharge in the Nitrogen ambience at 2kg/cm^2.
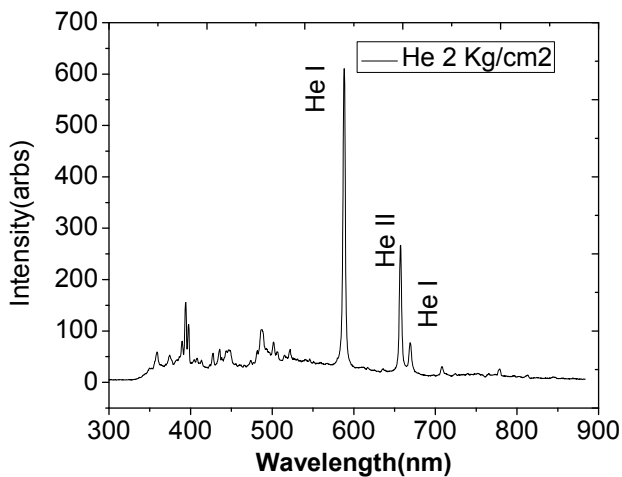
Figure-5: Optical emission spectra obtained during the spark gap discharge in the Helium ambience at 2kg/cm².

4. Lifetime Results:

Life-time profile of a particular emission wavelength, gives the instantaneous values of intensity and from which temperature can be estimated based on Boltzmann's distribution. Two atomic emission line intensities of Ar II at 434.8 and 487.9 nm were sampled at different instants and estimate the plasma temperature. Similarly the procedure continued for nitrogen and Helium gas line intensities to find the respective plasma temperature. The atomic emission lines and spectroscopic parameters used in estimating plasma temperature are summarized in Table1.

Line	Wavelength (nm)	Upper energy level E_k (c/m)	Configuration	g_k*A_k (1/s)
N II	500.5	186652.49	$2s^22p(^2P^0)3p-2s^22p(^2P^0)3d$	1.03e9
N II	567.9	166678.64	$2s^22p(^2P^0)3s-2s^22p(^2P^0)3p$	3.47e8
N I	746.8	96750.840	$2s^22p^2(3p)3s-2s^22p^2(3d)3p$	7.84e7
Ar II	434.8	157234.0196	$3s^23p^4(3p)4s-3s^23p^4(3p)4p$	9.36e8
Ar II	487.9	158730.2995	$3s^23p^4(3p)4s-3s^23p^4(3p)4p$	4.94e8
ArI	696.5	107496.4166	$3p^5(^2p^0)4s-3p^5(^2p^0)4p$ 3/2 1/2	1.92e7
Ar I	763.5	106237.5518	$3p^5(^2p^0)4s-3p^5(^2p^0)4p$ 3/2 3/2	1.22e8
He I	587.6	186101.592	$1s2p-1s3d$	8.83e7
He II	656.1	426717.460		6.27e6
He I	667.8	186104.966	$1s2p-1s-3d$	3.18e8

Table1. Spectroscopic parameters of Nitrogen, Argon and Helium used for plasma temperature

The life time was estimated at 1/e of the maximum emission intensity. The figures 6, 7, and 8 show the lifetime profiles of Nitrogen, Helium and Argon respectively. These figures show clearly the effect of pressure on the emission lifetime.
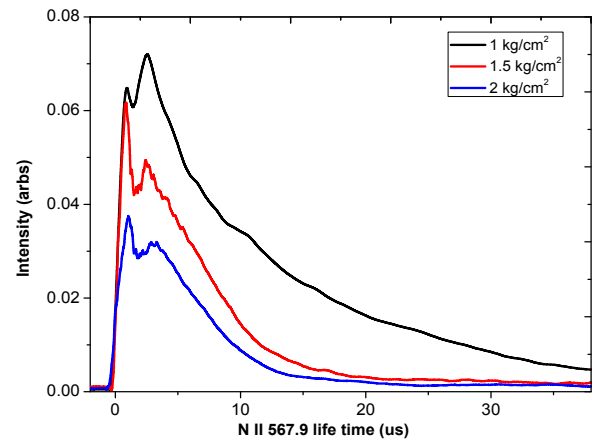

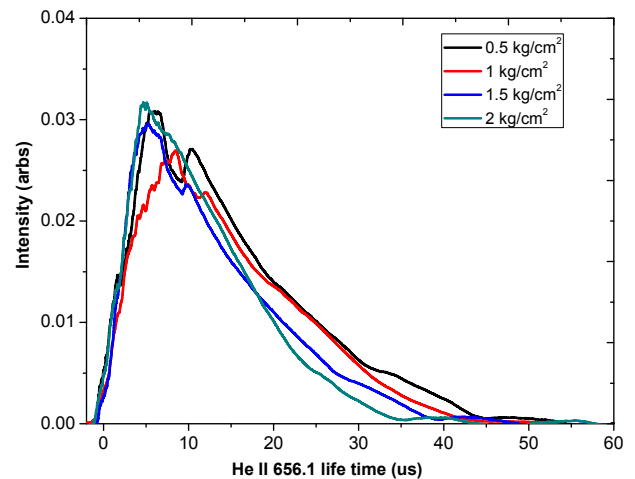**Figure-6:** Life-time profile of Nitrogen lines1kg/cm2 at NII 567.9

Figure-7: Life-time profile of Helium lines0.5-2kg/cm² at He II 656.1
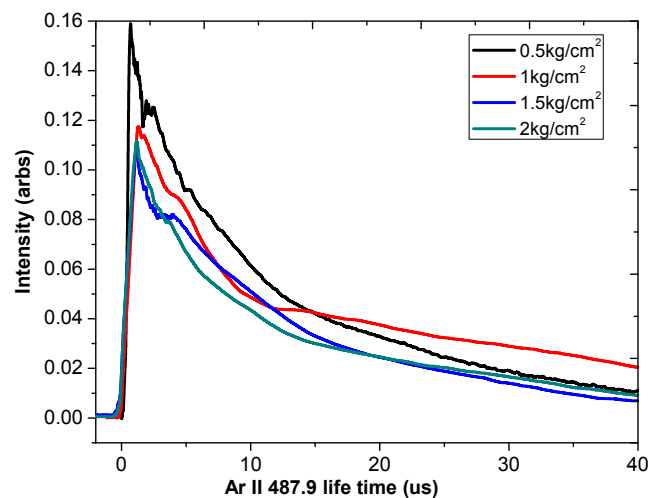

Figure-9: Life-time profile of Argon lines0.5-2kg/cm² at (d) Ar II at 487.9

5. ELECTRON DENSITY

Electron density can be determined using modified Saha equation [4] which involves ion-atom line intensity ratio. Based on the experimentally observed emission spectra, electron density, n_e.

$$n_e = \frac{I_a}{I_i} * 6.6 * 10^{21} \frac{A_i}{A_a} \frac{g_i}{g_a} \exp\left(\frac{E_{ion} + E_i - E_a}{T_e}\right)$$

Where E_i and E_a are the energies of the upper states, E_{ion} is the Ist ionization potential.

The Estimation of electron density considering local thermal equilibrium in Argon [5] ambient gas at 2 kg/cm^2 pressure value is shown in figure 10 and Estimation of electron density considering local thermal equilibrium in different ambient gases with various pressure values is shown in figure 11.
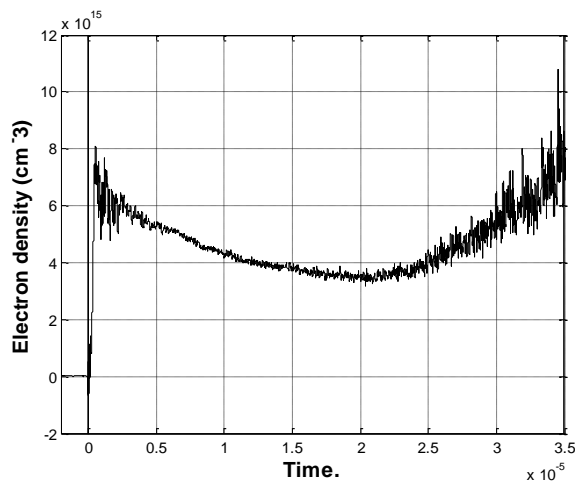

Figure-10: Estimation of electron density considering local thermal equilibrium in Argon ambient gas at 2 kg/cm^2 pressure value.

6. CONCLUSION

Optical emission spectroscopy is used to understand the discharge properties. Argon, nitrogen and helium gasses were used as dielectric medium at 0-2 kg/cm^2. It was observed that the electron temperature was high in the Argon compared with Nitrogen environment. The average electron density over the emission time was ranging from 10^9 to 10^{15} cm^{-3}. The plasma temperature and density estimated from time integrated spectra were an average value not giving any temporal distribution details.

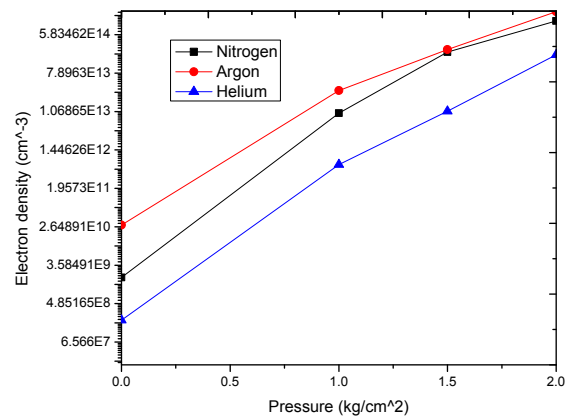**Figure-14:** Estimation of electron density considering local thermal equilibrium in different ambient gases with various pressure values.

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