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LOW TEMPERATURE AND LOW PRESSURE PLASMA FOR THE HWR SUPERCONDUCTING CAVITY IN-SITU CLEANING*

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Abstract

The glow discharge for low temperature and low pressures plasma were utilized for the half-wave resonator (HWR) superconducting cavity in-situ cleaning. The plasma was on ignition of the Argon/Oxygen mixture atmosphere, which was under the low pressure of 0.5 to 5.0 Pascal. Driven by the RF power with the frequency of the cavity fundamental mode, the plasma showed the typical characteristic of the typical RF glow discharge, which the temperature of the electrons about 1eV that diagnosed by the optical emission spectrum. The experimental parameters for the discharge were optimized to obtain the uniform plasma distribution on the HWR cavity, including the RF power, the atmospheric pressure and the oxygen proportion.

INTRODUCTION

Field emission in the superconducting radio frequency cavity is the major obstacle to operation at high accelerating gradients. The in-situ plasma processing developed at SNS has been proven to be an effective technology to solve the field emission issues for the elliptical cavities [1]. The low temperature and low pressure glow discharge, which was the chemically reactive oxygen plasma, was utilized to remove the contamination of hydrocarbons from the inner surface of the cavities at the room temperature.

The inert gas, as commonly using of argon and neon, mixed with few percent of oxygen as the working atmosphere was ignited by the RF power via the coupler. The plasma interaction with inner surface of cavity has two mechanisms: the ions bombarding the surface by physical sputtering progress, and the hydrocarbons chemically oxidized as the volatile substances desorption from the surface. The electric sheath between the plasma region and cavity surface with a bias voltage will accelerate the ions to bombard the surface. The bias voltage is determined by the electron temperature [2]:

$$V = -\alpha T_e . \qquad (1)$$

Where, Te is the temperature of free electrons in scale of eV and the $\alpha = \ln(2\pi m_e/M_i)/2$ is a constant value. For Ar^+ and Ne^+ the α is 4.7 and 3.5 [2]. In addition, the electron number density is a significance parameter for rates of plasma-surface interaction.

To understanding of the plasma discharge property in the HWR type cavity and the plasma interaction with niobium surface during the in situ cleaning progress, the investigation on the characters of electron temperature and number density was studied on a half wave resonator which used in the CADS project. The plasma properties were diagnosed by the optical emission spectrum method.

EXPERIMENT SETUP

The experimental platform was consisted of radio frequency system, vacuum system and the optical emission spectrum (OES) system, as shown in Figure 1.

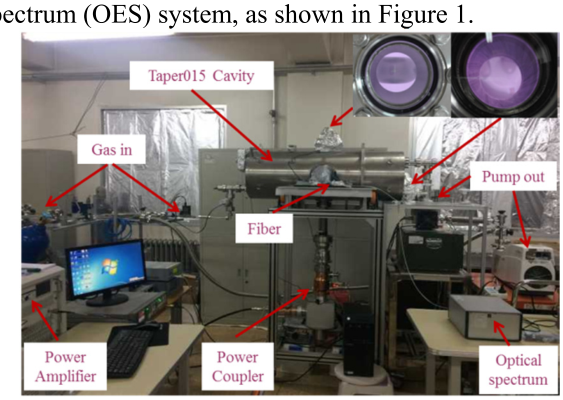

Figure 1: The plasma discharge experimental platform.

In order to be closer to the accelerator operation on the line, the type of Taper015 with the optimized beta of 0.15, which was used for CADS 25MeV linac, and a fundamental power coupler with the structure of dual ceramic windows were installed. However, the maxim of power amplify for this experiment was just 1kW, this value for operation on tunnel was 20kW. Thus the coupler antenna was adjusted for the coupling factor around 0.9.

The argon and oxygen were premixed with volume rate of 100: 3 under the control of two mass flowing controller (MFC). The premixed Ar/O_2 was fed to cavity through the third MFC. With help of pumping system, the gas pressure can be changed from 0.1 to 100 Pa on the cavity.

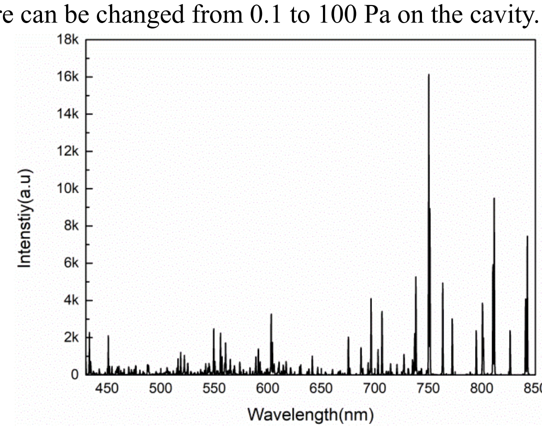

Figure 2: The OES spectrum of Ar/O_2 plasma discharge.

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The optical emission spectrum of argon discharge was collected with the wavelength of 430 to 860nm, as depicted in Figure 2.

RESULTS

Electron Temperature

The relative intensities of the characteristic lines emitted by excited argon atoms can be used to determine the excitation temperature (T_{ext}). This can give first estimation of the electron temperature in the low pressure under the assumption local thermal equilibrium (LTE) model [3-4]. The intensity of exited upper level for the characteristic line follows the Boltzmann law. The Boltzmann plot can be used to evaluate the Text as following equation:

$$\ln(\frac{I_{ij}\lambda_{ij}}{g_i A_{ij}}) = -\frac{E_i}{kT_{ext}} + C \ . \quad (2)$$

Where, λ_{ij} is wavelength emitted from the upper level i to lower level j, Iij is the intensity, and the A_{ij} is transition probability. The gi is the statistical weight and the E_i is the excitation energy for the upper level i. The k is Boltzmann constant and C is constant. In this work, 6 lines were chosen with wavelength of 703.0, 706.9, 720.7, 750.4, 751.5 and 763.5 nm, the parameters of those level were from NIST [5]. The plot and fitting is shown in Figure 3.

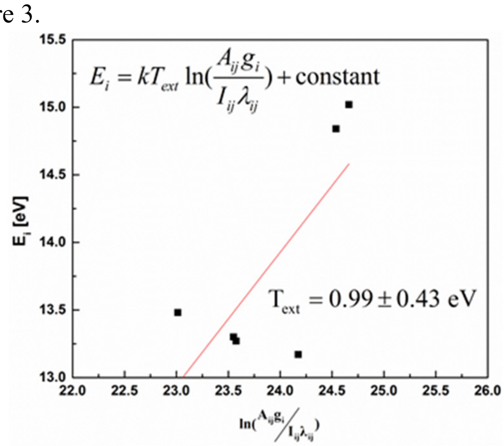

Figure 3: The Boltzmann plot to determine the excitation temperature by the LTE model, the error was taken from the standard deviation.

In the case of RF low pressure plasma, the electron number density and ionization degree is relative lower. The intensity of the excited upper level states cannot be assumed as the LTE model. The excitation mechanism can be described in the corona model. In this model, the excitation states were directly impacted from the ground state by the free electrons, and the spontaneous radiative emissions acted as the main depopulating progress. The balance equation can be written as:

$$n_e N_1 K_{1i} = Ni \sum_{i>j} A_{ij} \ . \quad (3)$$

Where the ne, N_1 and Ni are, respectively, the electron, ground level and excited state number densities. The density of Ni can be found from the line emission:$I_{ij} \propto A_{ij} \cdot N_{ij}/\lambda_{ij}$. K_{1i} is the free electron impaction excitation rate coefficient from the ground state to level i, and its expression is relative to the free electron temperature [6]:

$$K_{1i} = a_{1i} \times e^{-E_i/kT_e} \ . \quad (4)$$

Where, Te is the free electron temperature and the value of a1i are taken from the literature for this paper [6-7]. Using the equation (2) and (3), the electron temperature can be expressed as:

$$\ln(\frac{I_{ij}\lambda_{ij}\sum_{i>j} A_{ij}}{A_{ij}a_{ij}}) = -\frac{E_i}{kT_e} + D \ . \quad (5)$$

Where D is a constant, and the modified Boltzmann plot can deduce the T_e from the fitting slope, as shown in Figure 4.

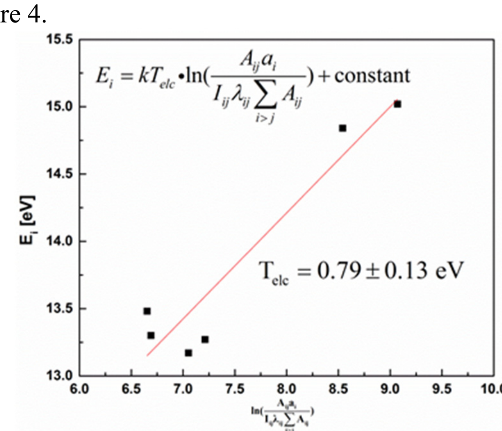

Figure 4: The modified Boltzmann plot to deduce the free electron temperature from the corona model.

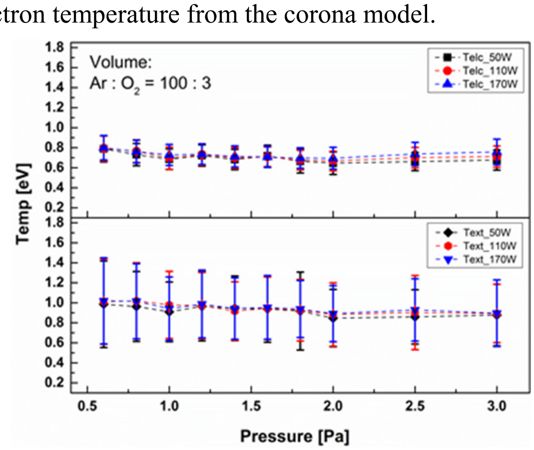

Figure 5: The excited temperature and the free electron temperature results for different pressure and RF power.

The results of the electron temperature from the optical emission model are as shown in Figure 5.

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Electron Number Density

The Saha-Boltzmann model can be used to evaluate the electron density by the intensity ratio of the Ar I (atom) and Ar II (Ar^+), two lines at 470.2nm for Ar atom and 472.6nm for Ar^+were chosen, as shown in Figure 6. The Saha-Boltzmann expression written as following [8]:

$$n_e = 4.83\times10^{21}\frac{I_0 A^+ g^+ \lambda_0}{I^+ A_0 g_0 \lambda^+} T_e^{3/2} \exp\left(\frac{-E_i + E^+ - E_0}{kT_{ext}}\right). \quad (6)$$

Where T_{ext} and T_e are, respectively, the excited and free electron temperature, E^+ and E_0 are upper level of the emission line. E_i is the ionization energy for Ar to Ar^+.The electron number density results are shown in Fig. 7.

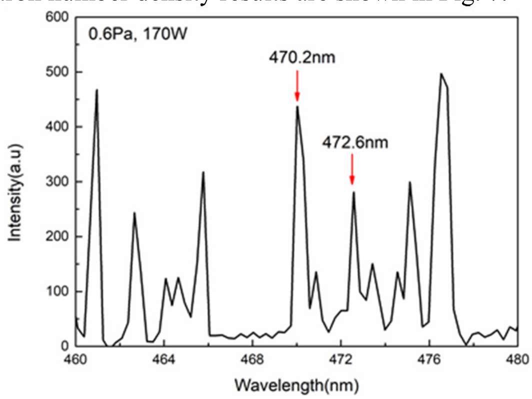

Figure 6: The spectral lines used in the estimation of the electron number density with Saha-Boltzmann equation.

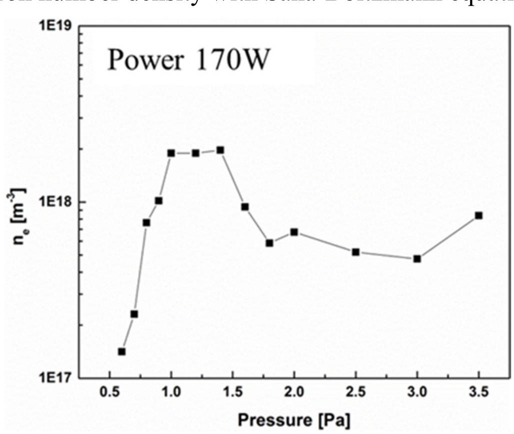

Figure 7: The electron density calculated from the Saha-Boltzmann model.

CONCLUSION

The property of the low pressure and low temperature plasma induce by the RF power has been investigated. In these temperature and density region, the plasma interaction with niobium surface will studied in the next work.

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