Plasma temperature measurement in a hybrid discharge by using optical diagnostics

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Abstract. Of the plasma methods used to improve the tribological properties of the solid surface [1-3], the treatment of metal pieces in the hybrid discharge, which is a combination of high voltage and electric arc discharges, seems very promising [4,5]. This method is developed in the Plasma Physics and Technology Laboratory at the Universidad Industrial de Santander (Colombia). In our work, the hybrid discharge is ignited in tungsten vapor. The plasma temperature and atomic composition of the discharge are measured through its optical spectrum.

1. Introduction
The hybrid technology of surface treatment includes two steps: the vaporization and ionization of metal atoms in an arc high current discharge and putting the obtained metal vapor under high voltage pulses. The samples to be treated serve as the cathode, thus being bombarded by a flow of high energy ions. So these ions turn to be responsible for modifying the surface characteristics. For the surface processing technologies, the atomic composition and temperature are the essential characteristics of the processing plasma. Some limitations of the electric probe methods in their use in the metal vapor discharges and their impossibility to determine the atomic composition prompt to resort to the optical diagnostics.

2. Experiment
The hybrid discharges are initiated in the MOSMET reactor [6-10] which is shown in figure 1. The reactor chamber of 70×70×80 cm\textsuperscript{3} is evacuated up to 0.1 mPa by a 1500 l/s turbo molecular pump. The cathode of the arc vaporizer disposed on the upper wall of the chamber (see figure 1) is made of 99.9\% pure titanium. Titanium as a treatment material is chosen because of its anticorrosive properties and compatibility with organic matter. The arc discharge current is maintained at a level of 150 A with a voltage of 30 V. The high voltage pulses are applied within the area between the cathode situated on the lower wall of the chamber and the chamber stainless walls. The 10 kV pulses are of 0.25 ms duration at 30Hz repetition frequency.
The spectral diagnostic system comprises an optical fiber cable which receives the discharge light and transports it to a DK480 spectrometer with a diffraction grid of 1200 mm\(^{-1}\) and a CCD Princeton Instruments camera of 1024×128 pixels. The optical spectra of the hybrid discharge are observed in two positions of the fiber optic receiver: in and outside the chamber. In the latter case the light emission of the discharge passes through the sapphire window in a lateral chamber wall on the fiber optic receiver.

3. Results and discussion

Figures 2 and 3 show the spectra emitted by the hybrid plasma in the above mentioned positions of the optical fiber receiver. The spectra, which are practically identical, are comprised of Ti and TiII lines, which evidences that the arc consists predominantly of ions and neutral Ti atoms. In these spectra, TiIII lines or ions of higher charges are not observed although there should be triple charge ions and even ions of a higher charge states in accordance with the Saha thermodynamic equilibrium formula in the arc discharge. The problem of detection of the multicharged ion spectral lines is related to the fact that these lines fall in the ultraviolet diapason where the sensitivity of the used spectrometric scheme falls down. For the ion implantation processes, it is important to determine which multicharged species are in the incident flux. In order to solve this problem, we are planning to expand the detectable spectral range to 200 nm.

The plasma temperature is calculated taking into consideration TiI lines and the parameters used for these calculations are presented in tables 1 and 2.

The plasma temperature is calculated by using the spectroscopic lines of titanium atoms TiI whose characteristics are presented in table 1 and table 2.

Here:

\[
I_{\lambda}^{kl} = F n_k A_{kl} = FC_k g_k \frac{e^{\frac{E_k}{kT}}}{U_s(T)} A_{kl}
\]  

(1)
$I_{ki}$ is the integrated intensity of a spectral line at a wavelength, emitted at the transition between the states $k$ and $i$, $C_s$ is the concentration of the radiative atoms, $F$ is the experimental parameter which determines the optic system efficiency to collect the radiation, $g_k$ is the statistic weight of the excited electronic state up to energy of $E_k$, $k_B$ is the Boltzmann constant, $T$ is the plasma temperature, and $U_s$ is the partition function for the radiative species.

Figures 4 and 5 show the behavior of the hybrid plasma temperature calculated in accordance with the data presented in tables 1 and 2.

As it is shown in figures 4 and 5, the temperatures calculated from the data obtained by the receiver placed in the chamber volume can be estimated as $7127 \pm 200K$ and by the receiver which is outside of chamber is $7574 \pm 200K$.

4. Conclusions and recommendations

The plasma temperature of a hybrid titanium discharge is measured with a spectroscopic method. The data obtained by two mentioned optical fiber receivers practically coincide and can be estimated as $7300$ K.

The present optical study was done through the spectral window of $480 – 540$nm and in order to identify the spectral lines of multicharged titanium ions (TiIII and TiIV), in case they exist, we are planning to increase the spectral range to 200-600nm.

![Figure 2. Spectrum obtained by the receiver situated in the interior of the treatment chamber.](image-url)
Figure 3. Spectrum obtained by the receiver situated at the exterior of the treatment chamber.

Table 1. TiI line characteristics obtained with help of the optical fiber receiver situated interior the discharge chamber.

| Wavelength [nm] | $I_{ki}$ [ua] | $E_{kk}$ [eV] | $g_{kk}$ | $A_{ki}$ | $\ln \left( \frac{I_{ki}}{g_k A_{ki}} \right)$ |
|----------------|--------------|--------------|---------|--------|------------------|
| 482.03396      | 3154.80143   | 4.0738       | 7       | 1.49E+07 | -10.40610       |
| 484.06795      | 6974.59070   | 3.4600       | 5       | 1.76E+07 | -9.44282        |
| 485.58196      | 6092.05817   | 4.8081       | 15      | 5.20E+07 | -11.76006       |
| 500.73246      | 13459.96140  | 3.2936       | 7       | 4.92E+07 | -10.14984       |
| 517.40183      | 9847.26358   | 2.3957       | 5       | 3.80E+06 | -7.56500        |

Table 2. TiI line characteristics obtained with help of the optical fiber receiver situated at the exterior the discharge chamber.

| Wavelength [nm] | $I_{ki}$ [ua] | $E_{kk}$ [eV] | $g_{kk}$ | $A_{ki}$ | $\ln \left( \frac{I_{ki}}{g_k A_{ki}} \right)$ |
|----------------|--------------|--------------|---------|--------|------------------|
| 482.03396      | 2350.30026   | 4.0738       | 7       | 1.49E+07 | -10.70048       |
| 484.06795      | 7044.73286   | 3.4600       | 5       | 1.76E+07 | -9.43281        |
| 485.58196      | 6092.05817   | 4.8081       | 15      | 5.20E+07 | -11.76006       |
| 500.73246      | 13373.87940  | 3.2936       | 7       | 4.92E+07 | -10.15626       |
| 517.40183      | 7364.04823   | 2.3957       | 5       | 3.80E+06 | -7.85558        |
Figure 4. Graph for the temperature calculations: the fiber optical receiver is interior of the discharge chamber.

Figure 5. Graph for the temperature calculations: the fiber optical receiver is exterior of the discharge chamber.

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