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Sputtering of the 1020 AISI steel in abnormal glow discharge

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Abstract. In all material treated in abnormal Glow Discharge (AGD) the phenomenon of sputtering occurs. In this work we study the sputtering suffered at different temperatures by AISI 1020 steel subjected to a DC discharge in two types of atmospheres. The steel samples were previously sanded until obtaining mirror brightness and subjected to the AGD plasma in the gaseous atmospheres of H₂ and Ar. The temperature for each sputtering process was set in the range of 420°C to 600°C. In these samples the mass variation was measured and the yield sputtering processes was determined. Next, the simulation of the sputtering process was performed in the SRIM/TRIM 2008 software, by adjusting sputtering yield computational computations to those experimentally measured, in order to determine the energy with which the responsible ions of the sputtering collide with studied target.

1. Introduction

Physical sputtering is the extraction of atoms from the surface of a solid due to the impact of the energetic particles [1]. Sputtering is present in any treatment performed with abnormal glow discharge. The process can be described as a moment transfer in a cascade of collisions initiated by the particle that impinges on the surface layer of the solid [2-5]. An atom is extracted from the surface if its binding energy to the surface is less than the energy of the incident ion. The sputtering yield is the parameter with which the process is quantified; it is a measure of the number of particles that are extracted from the surface by each incident ion. Then the physical sputtering depends on factors such as: Mass of interacting particles, its energy, angle of incidence, structural changes during the process [6] and roughness of the sample surface [7]. In the sputtering there is a transfer of mechanical energy through the exchange of the amount of movement between the ion, from the plasma of the glow discharge, and the atoms of the target [8]. The DC system is the easiest to perform sputtering. In it the particles ejected from the target (cathode) collide with the gas molecules and can be backscattering returning to the cathode or diffused in the opposite direction to the cathode depositing in the surfaces in front of the cathode. This since by the high gas pressure the mean free path of the ejected particles is less than the distance between the electrodes. It is estimated that about 90% or more of the sputtered material returns to the cathode by backscattering. The sputtering yield, i.e. the number of atoms removed from the target per incident ion can be obtained by the following empirical equation [9]

\[ Y = \frac{6.02 \times 10^{23} \times W}{M \times (I_d/1.6 \times 10^{-19}) \times t} \]  

(1)
where \( Y \) is the yield sputtering in atoms/ion, \( W \) is the mass lost by the simple in grams, \( M \) is the molar mass of the target material, \( I_d \) is the discharge current in amperes and \( t \) the time during which the target was subjected to the sputtering process in seconds. In this work, with equation (1), the sputtering yield of the 1020 steel was calculated in \( \text{H}_2 \) and Air glow discharges, and with this value, the energy of ions impinging the substrate was found, through the SRIM software [10].

2. Methodology
At the cathode of the abnormal glow discharge using confined geometry [11], AISI 1020 steel samples were subjected to the sputtering process. In order to compare the sputtering process in atmospheres of \( \text{H}_2 \) and Ar, discharges were generated in these two types of atmospheres under pressure of 2 torr and flow of 2scc/s. For this purpose, gases with 99.995% purities were used. The samples of 1020 steel were of cylindrical geometry with diameter of 10mm and height of 4mm and before subjecting them to the discharge were sanded and polished. A variable voltage pulsed DC source was used to initiate the discharge, the temperature of the cathode and the sample being adjusted to between 420°C and 600°C. The treatment time was 40 minutes. The samples were weighed before and after treatment, with a digital balance of 0.0001g resolution, and using equation (1) the rate of sputtering was determined. With the experimental value of the sputtering yield, using the SRIM 2008 software (TRIM), the energy of the ionic species responsible for sputtering was determined. The behaviour of the sputtering yield and its respective energy was observed as a function of the temperature for the two types of atmospheres. The samples surface after the sputtering process was also observed by optical microscopy.

3. Results
Figure 1 shows the behaviour of the current as a function of the voltage applied to abnormal glow discharge in atmospheres of \( \text{H}_2 \) and Ar to establish temperatures of 420°C, 500°C and 600°C. The increase of the current with the applied voltage, characteristic in the abnormal glow discharge [12], can be observed for the two atmospheres in Figure 1. For \( \text{H}_2 \) atmosphere is required higher voltages than for the Ar atmosphere, to reach the same temperature of the cathode. This because of the hydrogen atoms have a smaller mass, they must then have a higher velocity to impinging the cathode to transfer the necessary energy required to raise its temperature to the desired level. The temperature also increases with the voltage applied to the discharge as shown in Figure 2. This because of at higher cathode voltage more energetic particles impinges the cathode by raising its temperature. This allows correlate the behaviour of the temperature as a function of the voltage shown in Figure 2, for the two types of atmospheres, with that of the current versus voltage of Figure 1.

Figure 3 shows the behaviour of the mass variation as a function of temperature, with a higher loss of mass at higher temperatures for the same atmosphere due to the increase in the amount and energy of the particles impacting the cathode when the temperature is increased. This because of that the temperature is increased with voltage increases as mentioned above. Comparing the atmosphere type, there is a greater mass loss in the atmosphere with lower mass atomic species, similar behaviour observed for the sequence Xe, Kr, Ar where sputtering increases for less mass species [9].

The sputtering obtained by equation (1) is shown in Figure 4 as a function of temperature. A much higher sputtering yield is observed for the hydrogen atmosphere, atmosphere with smaller and energetic species as will be shown below.

Using the sputtering yield data of Figure 4, the energy for these values was adjusted using the SRIM 2008 software (TRIM), obtaining the energy of the particles responsible for sputtering as a function of the temperature shown in Figure 5. Thus, for the lightest species, energies of around 600eV were obtained, while for the heavier ones it was of the order of 30eV, differentiating by a factor comparable to the mass ratio \( (m_{\text{Xe}}/m_{\text{H}_2}) \) of the two gaseous species. This higher ionic energy reached in the atmosphere of hydrogen is correlated with the greater voltage necessary to establish the respective temperatures as shown in Figure 2.
**Figure 1.** Current vs discharge voltage in hydrogen and argon atmospheres (Flow=2scc/s at 2torr).

**Figure 2.** Temperature vs discharge voltage in hydrogen and argon atmospheres (Flow=2scc/s at 2torr).

**Figure 3.** Sample lost mass vs temperature hydrogen and Argon (Flow=2scc/s at 2torr).

**Figure 4.** Sputtering yield vs sample temperature in hydrogen and argon atmospheres (Flow=2scc/s at 2torr).

**Figure 5.** Ionic energy during the sputtering vs sample temperature in hydrogen and argon atmospheres (Flow=2scc/s at 2torr).

Figures 6 and 7 show the micrographs at 1000X of samples surface subjected to sputtering in H\textsubscript{2} and Ar atmospheres, respectively, at different temperatures used. In the samples subjected to a
temperature of 420°C and 500°C in H\textsubscript{2} (Figures 6(a) and 6(b)) an incipient development of the microstructure of the material can be observed. These surface patterns disappear for the other surface (Figure 6(c)), possibly due to the greater energy of the incident particles that promote inner erosion of the sample. This can be sustained by the greater mass loss of this sample. In contrast, samples treated under argon atmosphere (Figure 7) reveal a surface pattern that could be a reveal of part of the microstructure of the material, due to the relatively low energy of the incident argon ions interacting with the surface region of the sample. The above suggests that these atmospheres can be controlled to promote the reveal of the microstructure of AISI 1020 steel.

![Figure 6](image6.jpg)

**Figure 6.** Surface optical micrographies at 1000X of samples treated in the glow in H\textsubscript{2} at temperatures of a) 420°C, b) 500°C and c) 600°C (Flow=2sec/s at 2torr).

![Figure 7](image7.jpg)

**Figure 7.** Surface optical micrographies at 1000X of samples treated in Ar at temperatures of a) 420°C, b) 500°C and c) 600°C (Flow=2sec/s at 2torr).

4. Conclusions
The sputtering process of the AISI 1020 steel was studied in two atmospheres used for the treatment of materials in the abnormal glow discharge as a function of temperature, with a higher cathodic sputtering yield in the H\textsubscript{2} atmosphere of lighter species. This is due to the greater energy that must be printed through the voltage to reach temperatures similar to those easily reached with Ar. This energy was determined using the SRIM/TRIM 2008 software. The cathodic sputtering yield also increases with the sample temperature due to the particle shock mechanism at the cathode used for its control. On the other hand, these atmospheres are potentially applicable for reveal of the microstructure of the AISI 1020 steel samples.

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