APPLICATION OF PLASMA CLEANING TO CAVITIES PROCESSING

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Abstract

Atmospheric-pressure plasma treatment is an emerging, very versatile and inexpensive technique used in a variety of surface processes such as dry etching, surface treatments and modification of surface wettability. After initial studies on different configurations of RF, MW and DC atmospheric plasma devices we have analyzed the modification of water wettability induced by helium atmospheric plasma.

We have applied a resonance atmospheric plasma cleaning step to further clean a 6 GHz Nb seamless cavity observing an increment in the Q_0 from 7×10^6 to 2×10^7 in only 30 minutes of process. The increased wettability due to the plasma action on the inner cavity surface has proved to enhance the beneficial action of water rinsing pushing the Q_0 value further up close to 3×10^7.

INTRODUCTION

A big part of the research in the SCRF particle accelerator physics aims to improve the performances of the superconducting cavities increasing the Q_0 value and the accelerating field by mainly working on the inner surface etching and cleaning processes.

We have started the investigation of a simple, reliable and easy to set up atmospheric plasma treatment based on changing the energy of the inner cavity surface that after the treatment become extremely hydrophilic. On the 2 extreme regions of the wettability regime the surface presents self-cleaning properties, this is a well known phenomenon already used in high tech industries. Surface extreme hydrophilicity, with a loto leaves-like effect, can be obtained by creating double roughness microstructures; the super hydrophilicity can be reached using plasma treatments. In Figure 1 we report the differences in contact angle between a clean Nb surface (10 minutes ultrasonic rinsing with soaps plus 10 minutes with pure water) and an atmospheric plasma treated Nb surface. The plasma treated side show a very high wettability with a contact angle barely measurable.

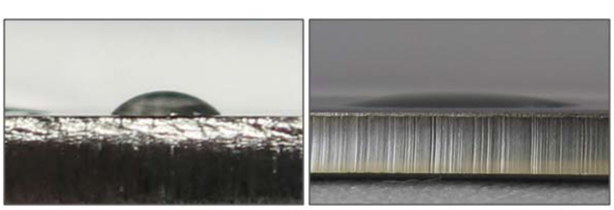

Figure 1. Surface contact angle modification, on the right a Nb clean surface, on the left the barely visible drop on the Nb surface after an atmospheric plasma treatment of 5 minutes.

The modification of the surface hydrophilicity / hydrophobicity and hence water wettability is a mechanism widely studied in the nanotechnology field and in material science. Plasma treatment is one of the most versatile techniques used for such surface modification. It is also widely used to alter the surface properties of materials in a number of applications like improving adhesion of coatings to metals and polymers [1], increasing wettability and printability of polymers [2, 3], enhancing biocompatibility of implants [4], and in the manufacturing of semiconductor devices [5, 6].

EXPERIMENTAL DETAILS

A resonance TM010 mode atmospheric plasma has been ignited inside a Nb 6 GHz cavity at room temperature under an helium flux of approximately 15 l/minute.

The experimental apparatus used to treat the cavity is illustrated in Figure 2, during the plasma treatment helium was fluxed at atmospheric pressure inside the cavity through the pumping line and extract from the cavity by a dedicated exaust line.

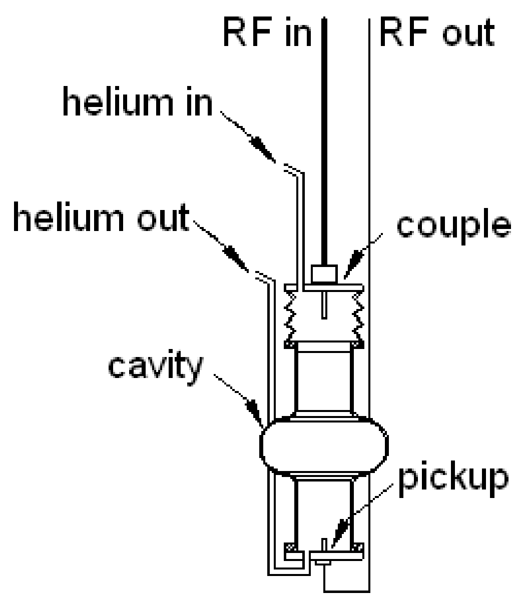

Figure 2. Experimental configuration of the 6 GHz cavity used for the atmospheric plasma treatment.

The plasma power has been kept constant at 8 W and during the treatment the cavity temperature was stable at 50°C. We've done three treatments: two of 30 minutes and the last of 10 minutes of ATM plasma plus 10 minutes of ultrasonic cleaning, in order to investigate the cleaning properties of sonic waves on a plasma enhanced hydrophilic surface. Q_0 vs. E_{acc} were measured after each treatment session.

RESULTS

The Nb 6 GHz cavity has been initially prepared with 1 hour BCP 1:1:2, 1 hour EP, 4 hours baking at 900 °C with Ti used to getter the hydrogen and finally with a BCP 1:1:2 for 3 minutes to get rid of the Ti contamination. The cavity has then been measured showing a starting situation Q_0 of 7×10^6.

After the initial standard treatments the cavity underwent 30 minutes of resonance atmospheric plasma with just helium as process gas and the Q_0 increased to 2×10^7. A successive second treatment of 30 minutes on the same cavity didn't show any further improvement.

A third plasma treatment has been carried on for 10 minutes and right after followed by an ultrasonic rinsing with deionised water. The Q_0 rose to $2{,}8 \times 10^7$, the error for all the measures being 10%. The time decay passed from 1×10^{-4} s of the initial situation to $2{,}7\times10^{-4}$ s after the first and second treatment to $3{,}7\times10^{-4}$ s after the ultrasonic rinsing.

The max electric field gradient has also been improved going from 2,5 MV/m to 3,7 MV/m. The results are reported in Figure 3 and in Figure 4.

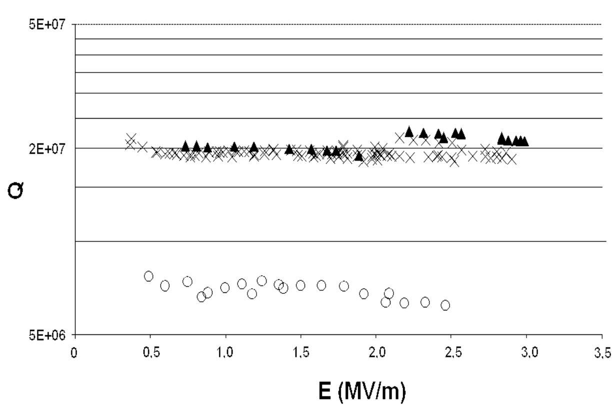

Figure 3. Q vs. E_{acc} of the Nb 6 GHz cavity treated with atmospheric resonance plasma. ○ starting situation; × 30 minutes plasma treatment; ▲ 60 minutes plasma treatment.

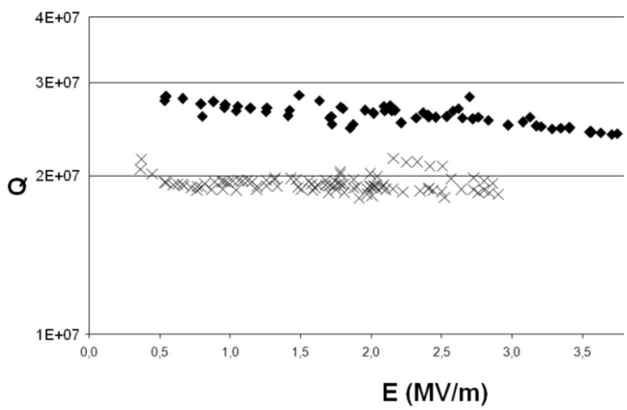

Figure 4. Q_0 increment after the third treatment. × 30 minutes plasma treatment; ♦ 10 minutes plasma plus 10 minutes ultrasonic rinsing.

DISCUSSIONS

Water wettability

Our initial study concerned the individuation and construction of the right plasma source by which it would have been possible and easy to treat the internal part of an accelerating cavity. The sources, characterized by a different plasma power, ignition mechanism and plasma shape, have been already described [7].

The effect of a 5 minutes treatment on different substrates has been analyzed using the sessile drop method and measuring the contact angle of a 300 µl deionised water droplet. An increment in hydrophilicity and wettability is evidenced by the decrement in the contact angle, phenomenon that has been observed for all the substrates analyzed as presented in Table 1.

Table 1: Contact Angle modification induced by a plasma treatment of 5 minutes ignited with helium in a free air volume.

Substrate	C.A. pre-treatment	C.A. post-treatment
Nb	42	9
Si	52	6
Cu	45	13
Quartz	32	7
Teflon	66	38
Polystyrene	71	20

The contact angle modifications are similar with all the atmospheric plasma sources that we have studied and all of them present a very similar optical emission spectrum, shown in Figure 5. There are signals of helium, the carrier gas, and of oxygen and nitrogen present as contaminants. The increment in water wettability (hydrophilicity) can be due to the oxidation of carbon contaminants on the surface by the chemical activated hydrossile anion OH^- and radical oxygen $O^{\bullet}$ but also to the creation of polar sites by the charged species formed in the plasma. Another explanation, related to the former one, is that the surface energy increases after the plasma treatment and the formation of a solid-liquid contact area is energetically favorite if compared to the solid-gas one. The changing in surface energy can also be responsible for a different interaction between the solid and the adsorbed gases that can desorb leaving a cleaner surface.

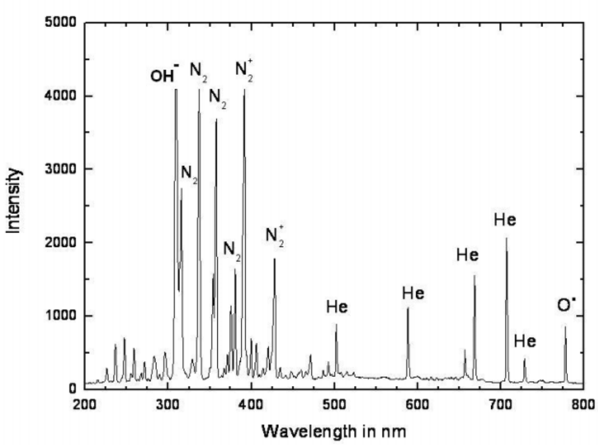

Figure 5: Optical Emission Spectrum of atmospheric plasma ignited by the plasma needle source at a power of 5 W using helium in free air.

Resonance plasma

The shape of the plasma inside the cavity is determined by the electric and magnetic field of the excited fundamental mode. The electric field module is the highest in the centre of the cell while the magnetic field has its highest module in the border region of the cell, as reported in Figure 6.

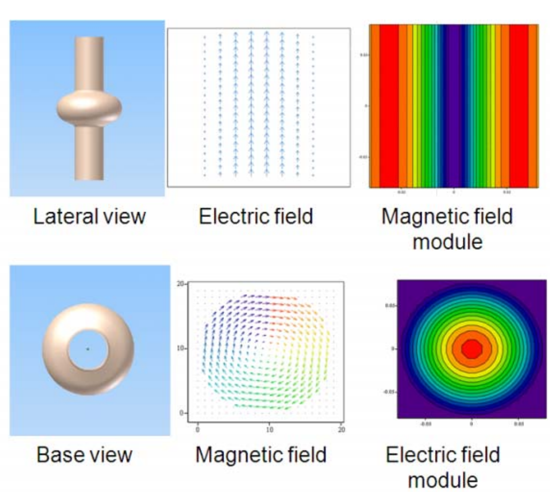

Figure 6: Magnetic and Electric field distribution of the fundamental mode TM010 referred to a tesla cavity.

With this electrical and magnetical field distribution the plasma assume a spherical shape centred in the cavity and that has the capacity to uniformly treat all the inner surface of the cell.

Surfactants analogy

Surfactants that are present in soaps have the property to increase the surface wettability by shielding the water intermolecular interactions and hence decreasing the surface tension. Water with surfactants can this way better spread on the surface that has to be cleaned and the cleaning action can be done more effectively also in the small interstitials volumes which would otherwise not be treated by a liquid with low wettability and high surface tension. So a high wettability is a synonym of high interaction between the solid and the liquid. This high interaction can be also achieved by using atmospheric plasma with the advantage that it doesn't leave contaminants on the surface as it happens with soaps.

In our experiment the cleaning process has been enhanced by the ultrasonic rinse whose action has been made more effective by the high wettability of the cavity internal surface.

CONCLUSIONS

Helium low power Atmospheric plasma treatmet on Nb superconducting cavity has been proved to be beneficial for Q_0.

Atmospheric Plasma make the Nb surface hydrophylic and a following rinsing become even more beneficial for Q-value

FUTURE DEVELOPEMENT

More experiments will be carried on 6 GHz cavities exploring the effects on rinsing time and helium flux variation. The atmospheric plasma cleaning process will be also studied on 1.3 GHz tesla cavities in order to explore its effect when the ratio ionization volume/cell surface decreases.

The chemical activation by atmospheric plasma gives also the possibility to add reactive gases in the carrier flux and investigate the etching rate due to chemical activated fluorine ions coming from mixture of CF_4, NF_3 with and without oxygen. These gas mixtures have already successfully been used to etch Nb in the semiconductor industry for the realization of Josephson junctions [8],[9].

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