# EFFORTS OF THE IMPROVEMENT OF CAVITY Q-VALUE BY PLASMA CLEANING TECHNOLOGY: PLAN AND RESULTS FROM CORNELL UNIVERSITY

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*Abstract*

We reported the plasma works at Cornell University. The plasma has been generated for 1) surface cleaning to reduce field emission; 2) the cavity quality factor improvement. The experiment design, including RF design, the gas type and pressure selection, the external DC magnetic field calculation, had been discussed. The plasma experiment set-up by using a 1.3GHz single-cell cavity is shown. Argon and helium plasma was successfully ignited in the cavity; the results of the plasma processing will be displayed.

## INTRODUCTION

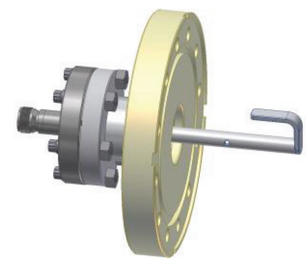
Experience with larger SRF installations shows that occasionally SRF cavities have substandard performance, and an in-situ cleaning mechanism would be highly desirable to recover the performance. Plasma cleaning was successful in reducing field emission in cavities with poor performance [1]. Potentially, it might also be able to improve the quality factor $Q_0$ not only by reducing field emission, but also by removing bad oxides or other surface contamination. Within this proposal we would study if in-situ plasma cleaning can be effective in recovering or even improving the medium field $Q_0$ of SRF cavities.

## DESIGN OF THE PLASMA EXPERIMENT

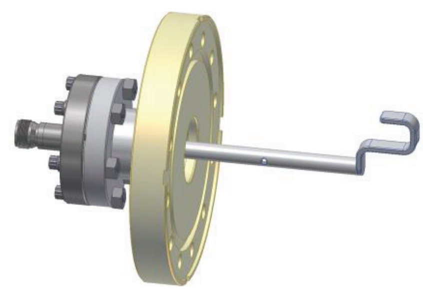
### *RF Design*

As the plasma project has two goals: 1) reducing the field emission; 2) The Q-value improvement. The selection of RF modes has been considered, because the plasma only concentrates in E-field region but not in B-field region. For the Q-improvement purpose, the plasma should treat the surface on the cavity equator region; hence the RF modes should have E-field distribute on the equator region. The fundamental mode of a 1.3GHz cavity is TM010 which has E-field concentrating on the iris region but not the equator. Therefore the TM010 can be only used for the cleaning purpose. Several higher-order-modes have been considered as candidates for the Q-improvement: TM011, TE111, and TE211modes. They have E-field components on the equator.

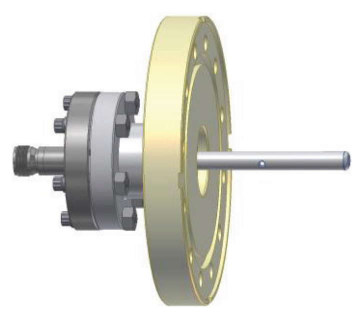
The couplers of those modes have been designed to transfer the RF power into the cavity without causing RF break-down in the transmission line. Sine we have several modes to excite, both the hook antenna and straight antenna have been designed, shown in Fig. 1.



(a) The hook antenna for TE111 and TM011 mode



(b) The hood antenna for TE211 mode



(c) The straight antenna for TM010 mode

Figure 1: Hook antenna and straight antenna designed for TE111, TE211, TM010, and TM011 modes.

The external Q versus antenna length curves for three types of couplers is displayed in Fig. 2. Since we treated the cavities at room temperature, the $Q_0$ of the cavity was around 5000. The plasma will consume RF power as well; hence the Q-value of the whole system could be even low to 1000. The external Q should match the system Q keeping the reflection power minimum. For our works, we selected the $Q_e$ is about 7e3 marked by the red rectangular in Fig. 2, because the antenna should not be too close to the cell.

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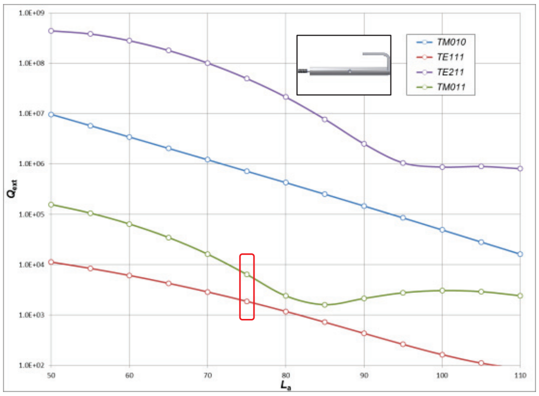
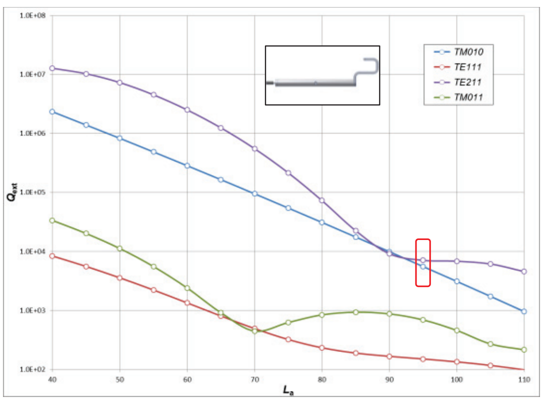
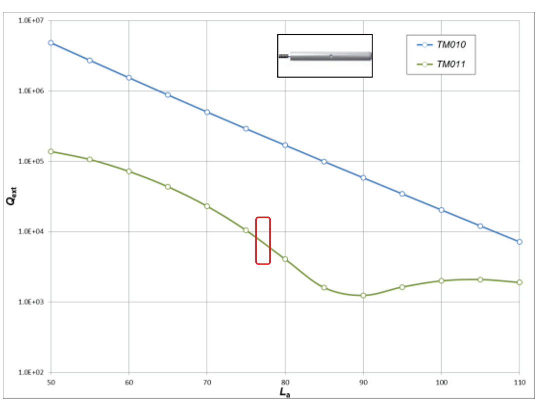



(a) The hook antenna for the mode TM011 and TE111




(b) The hook antenna for the mode TE211




(c) The straight antenna for the TM010

Figure 2: External Q versus antenna length of three types of coupler for TE111, TE211, TM010, and TM011 modes.

We started the plasma with pure argon gas and helium gas. From the Paschen's law and the reference [2-3], it's possible to calculate the minimum gradient, which is about 40KV/m, to ignite the argon and helium plasma when the pressure is in the range 20-40mTorr. The peak surface gradient can be converted into the accelerating gradient by factor 2 for the TESLA shape cavity. The input RF power then can be calculated by Eq. (1),

$$E_{acc} = \frac{1}{d}\sqrt{\left(\frac{R}{Q_0}\right) Q_0 P_{in} \frac{4\beta}{(1+\beta)^2}}. \quad (1)$$

here $d$ is the distance between two irises, $\beta$ is the coupling factor, $P_{in}$ is the forward RF power. Including the cable loss, the relation between the $E_{pk}$ and the input RF power is plotted in Fig. 3. The maximum output RF power of our amplifier is 200W, which is able to establish 40KV/m peak surface gradient in the cavity at room temperature. But the margin is very tight, the only way to increase the $E_{pk}$ is reducing the coupler external Q, i.e., increasing the antenna length. But it will cause other problem which will be described in the next section.

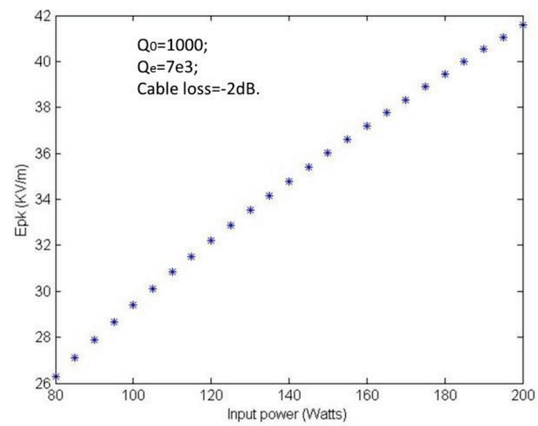



Figure 3: The peak surface gradient versus the input RF power.

## *DC Magnetic Field*

The plasma can be generated only by RF power which is so called RF plasma. It requires high RF power and sophisticated coupler. DC magnetic field can reduce the generation condition of the plasma which is called electron cyclotron resonance (ECR) plasma [4]. The DC magnetic field can extend the electrons life-time to sustain the plasma in high efficiency. The scheme of the ECR plasma is shown in Fig. 4. Two permanent magnets are placed on the side of the cavity. The B-field is perpendicular to the E-field.

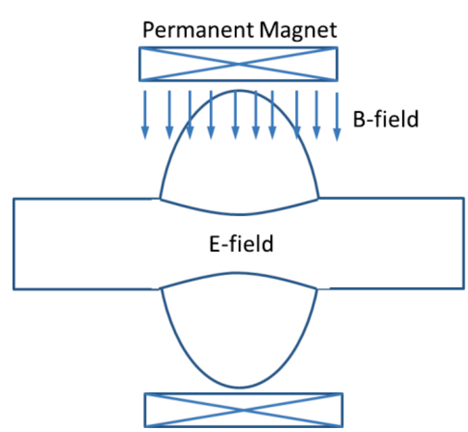



Figure 4: Scheme of the ECR plasma.

The B-field strength can be determined by the Eq. (2),

$$B = \frac{\omega\, m}{e}, \quad (2)$$

here $\omega$ is frequency of the cyclotron electron, $m$ is the electron mass, $e$ is the charge. For a 1.3GHz cavity, the $B$ is about 500 Gauss.

## PLASMA EXPERIMENT SET-UP

The experiment set-up is shown in Fig. 5. The coupler connected to one end of the cavity; the vacuum/gas line connected to the other end with a T-connector. The view port was installed along with the cavity beam axis. Two temperature sensors were attached on the cavity iris and equator wall.

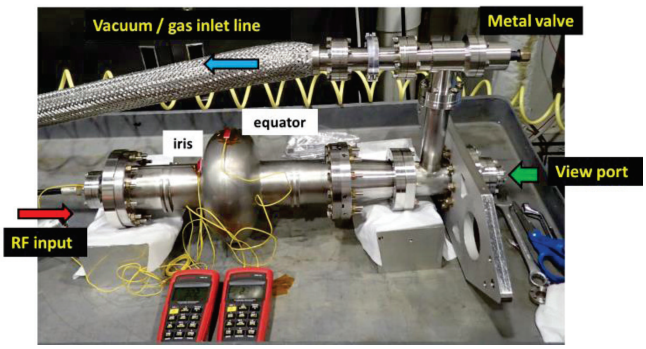



Figure 5: Plasma experiment set-up.

As the first step, we started with TM010 mode, the frequency of which is 1.3GHz. When the plasma has been ignited in the cavity, the images were taken from the view port to evaluate the plasma quality displayed in Fig. 6. Comparing the bright and dark rings, the location of the plasma can be known. In ideal case, the plasma should be generated in the cell but not in beam pipe or feedthrough. In Fig. 6, the plasm, for example, was generated in the feedthrough region, where could damage the ceramic window of the feedthrough if the RF power was too high.

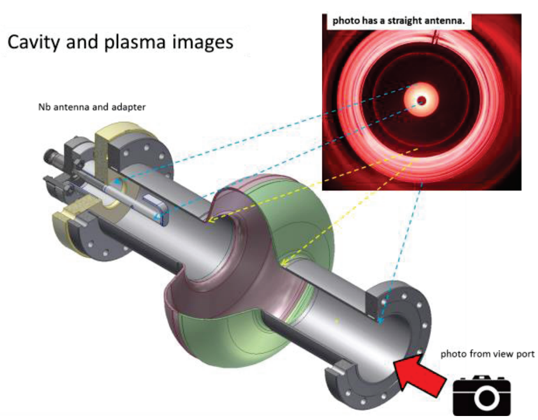



Figure 6: Plasma locations observed in a single-cell cavity.

Two permanent DC magnets was applied, the B-field was about 500Gauss. Varying RF power and gas pressure, it can obtain different energy level plasma, shown in Fig. 7. Here we evaluate the energy of plasma by colours which were changed from red to violet from RF power 41W to 130W as well as the gas pressure was decreased from 200mTorr to 0.1mTorr when the RF power was 130W. The violet plasma is regarded as the highest energy level. The temperatures on the cavity wall indicate the plasma energy level as well. When the high energy plasma was ignite in the cavity cell, the temperature on iris will be dramatically jumped up to 70C within 20min. The temperature measurement results are consistent with the colour of the plasma.

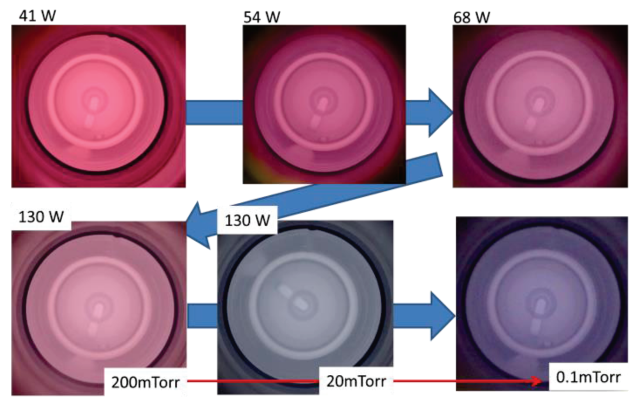



Figure 7: The plasma at different energy level with a series of RF powers and gas pressures.

We put series of marks along antenna to evaluate the effectiveness of the plasma processing. Figure 8 shows the comparison of the before and after processing. The marks were treated by the plasma about 2hours. It is very clear that some of the marks can be completely removed by plasma processing. The colour of the rest marks has been diluted.

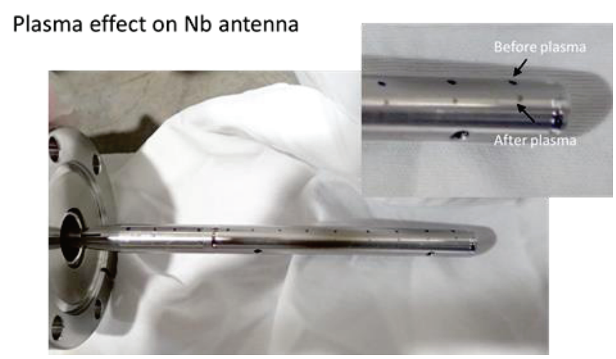



Figure 8: The comparison of before and after plasma processing.

## THE LIMITAION AND NEXT SETP

We still have some limitations of the RF coupler. First of all the operation gas-pressure should be very low (<0.1mTorr) to avoid the plasma to be excited in the beam pipe and feedthrough. The reason is the E-field concentrates in the transmission line shown as the red colour in Fig. 9. The low gas pressure increases the plasma generation condition; hence the plasma cannot be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ignited in those regions. But in the cell region, the condition has been decreased by the DC magnets. However, this will cause some limitation if we continue increasing the input RF power which implies the pressure should be decreased correspondingly. Too low pressure will dramatically reduce the efficiency of the plasma. At this point of view, our next step is to optimize the coupler structure to reduce the E-field in the transmission line.

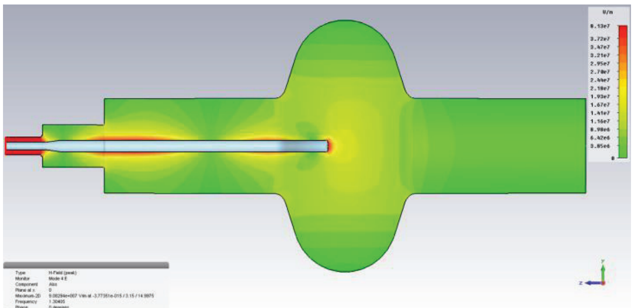

Figure 9: The E-field distribution in the RF coupler and cavity.

## CONCLUSION

The plasma system has been designed; the Argon and helium plasma was successfully generated in the single-cell cavity at different RF powers and gas pressures. The plasma effectively removed the marks on the antenna. The RF coupler imitated the energy of the plasma. Optimization of the coupler structure is our next step.

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