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University of Wisconsin-Synchrotron Radiation Center **TECHNICAL NOTE**	**File No.** **xxx**	**Page** 1 of 8
Subject: **Plasma Processing Of a 200 MHz Superconducting RF Electron Gun, Revision 2**	**Author(s):** **R. Legg, M. Fisher, K. Kleman** **Date:** **17March2013**	

Abstract:

The University of Wisconsin is developing a 200 MHz quarter wave resonator SRF electron gun. The cavity itself was constructed by Niowave Inc. During the initial cold tests at Niowave in Feb 2012, the cavity showed a very good no field Q0 of 3E9 at 4K, indicating good niobium in the cavity. However, the cavity exhibited relatively severe field emission which limited operation to approximately 13% of the design peak cathode gradient of 40 MV/m. Field emission is most often the result of a contaminated surface [2]. After the cavity had its helium vessel welded on, the cavity was high pressure rinsed (HPR) again, but no second cold test was done.

To improve the anticipated initial performance, a novel surface preparation technique, plasma processing, developed at the Spallation Neutron Source[3] and JLAB[1] was used on the cavity. The technique, in essence, establishes an Ar:O plasma in the cavity which 'ashes' any contaminants left on the surface after the high pressure rinse.

The technique of establishing a plasma in the cavity was initially tested using a helium plasma since it has been shown [5] not to degrade cavity performance and was deemed much less likely to damage the cavity. The tests were performed Oct. 30, 2012. The test also allowed us to refine the spectroscopic technique of looking for contaminants in the plasmas produced.

Two weeks later a series of cleanings using Ar:O were performed. This tech note describes the procedure and the results achieved.

Introduction

The University of Wisconsin is developing a 200 MHz quarter wave resonator SRF electron gun under DOE contract. The cavity itself was constructed by Niowave Inc. During the initial cold tests at Niowave in Feb 2012, the cavity showed a no field Q0 of 3E9 at 4K, indicating good niobium in the cavity. However, the cavity exhibited field emission which limited operation to approximately 13% of the design integrated gradient of 4MeV, Fig. 1. Field emission is most often the result of a contaminated surface [2].

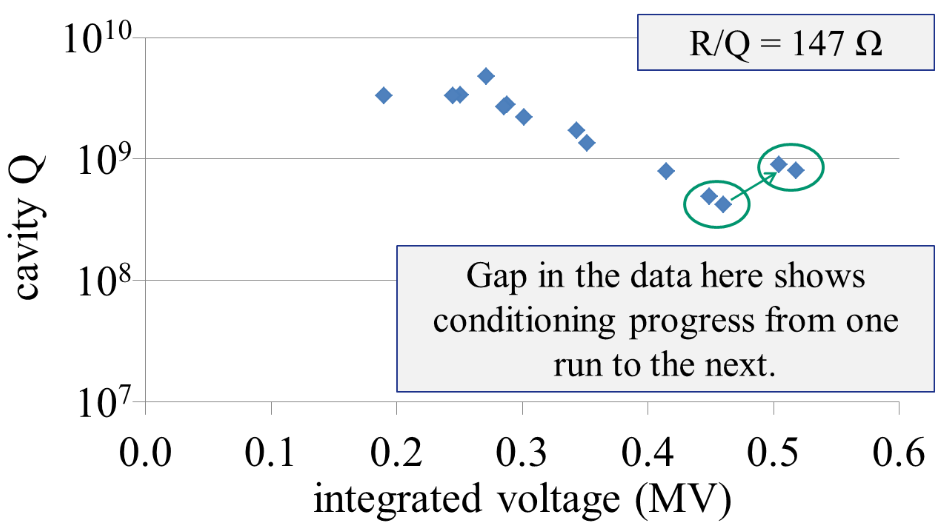

Figure 1. Initial 4K test results for cavity. Nominal integrated voltage is 4 MeV. Integrated voltage was inferred from the forward directed radiation spectrum.

In order to improve this result, a new technique for cavity processing developed at JLAB and SNS was used on the cavity. The technique generates an Ar:O plasma in the cavity which 'ashes' contaminants left on the cavity surface after chemical processing. This procedure was selected rather than conventional HPR since the cavity with the helium jacket welded in place is too large for HPR booths at JLAB and SRC would have had to build up the entire ultra pure water and high pressure pump infrastructure to do it in house. In addition, the cavity in the helium vessel was too large for any vertical test facility. Plasma processing could potentially be done in-situ if the cavity was found to still have high field emission during commissioning. A special antenna with better coupling was fabricated for the tests. A window which allowed the plasma to be monitored spectroscopically was also installed on the port.

Initial tests were performed with helium, since it has been shown to not damage the surface of cavities during processing[5]. After the plasma initiation process was well understood and the use of the spectroscope optimized, Ar:O was used to process the cavity. The oxygen in the mixture combines with carbon contaminants on the cavity surface to form CO, which can then be pumped from the cavity.

Technique

The technique used is to flow the gas through the cavity at a pressure of 10 to 100 millitorr and then strike a plasma in the cavity using an rf field. In our configuration, no cathode stalk is present, so the hole in the cathode nose cone acts as an rf filter with an attenuation of 40 dB at the resonant frequency of the cavity. Exploiting that fact, we introduce the gas through the cathode orifice and pump through the anode port behind the coupling antenna. In this fashion, we introduce gas into the cavity without concern of a plasma being struck outside the cavity.

A frequency synthesizer is used to vary the frequency and level of the input signal and a spectrum analyzer and directional coupler are used to monitor the forward and reflected power. A special antenna is used which is inserted through the cavity anode port, Figure 3. This antenna has very good coupling to the plasma allowing much lower rf power to be used. Typical power levels for the process are less than 100 watts allowing a 100 watt solid state amplifier to be used for the drive.

A sapphire window is installed at an angle on the same flange the antenna passes through on the anode port along with a port to pump the gas from the cavity. An extended range fiber guide and USB controlled spectrometer[6] are attached to the optical window. Using this the intensity of the CO emission line at 520 nm is monitored for reduction during the plasma process. From literature produced by the semiconductor industry [4], CO intensity should drop by 2x over the course of the etch process. The intensity of the 520 nm line is only about 0.02% of the Argon lines in the spectrum, so careful choices for the integration time, averaging number and boxcar window used in the measurement are necessary, along with background and detector offset subtraction. The best results were achieved with a 10 sec integration time per point, a 3 bin smoothing on the boxcar with background subtraction turned on. No averaging of multiple spectra was used due to the long integration times.

Experimental Apparatus

The gas handling system: A schematic of the gas handling is shown in Figure 2.

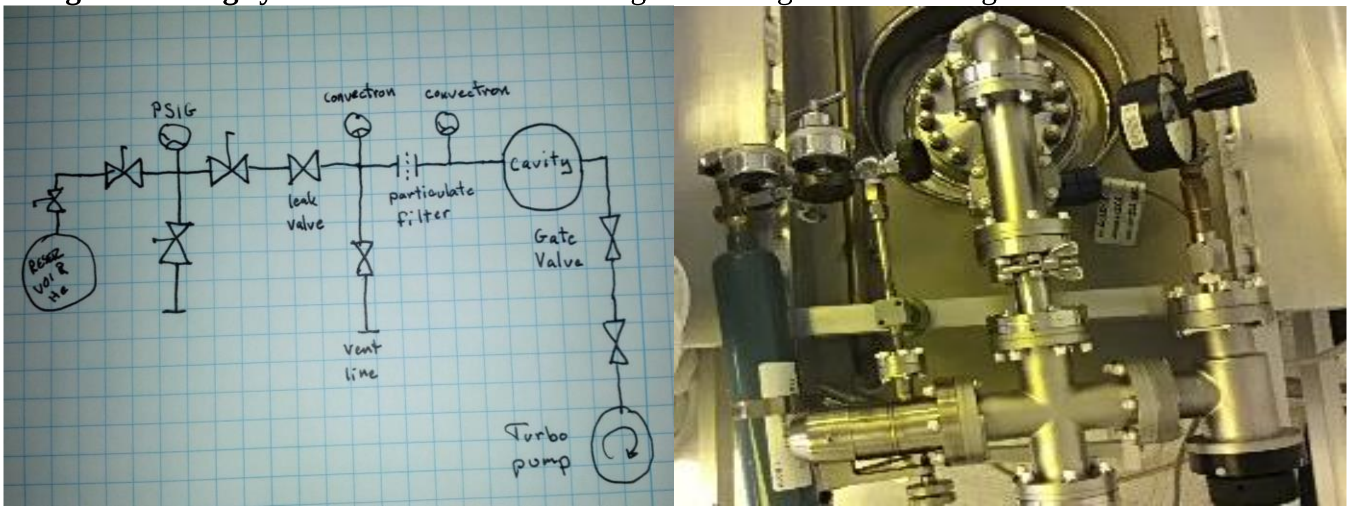

Figure 2. Schematic and photo of gas handling system.

The system allows the cavity to be pumped out by the turbo pump using the gate valve as isolation. Either helium from the demonstration bottle in Figure 2 or the 10:1 Ar:O mixture used for the processing of the cavity can be flowed through the cavity using the leak valve and the 0.3 micron particle filter. The cavity can also be vented using boil-off nitrogen through a right angle valve and the 0.3 micron filter. The use of two convectron gauges allows the pressure on both sides of the filter to be monitored, although the readback curves for the pressure will need to be corrected for the different gases. Using the leak valve allowed fine control over the pressure and leak rate through the cavity. By allowing a second input point upstream of the leak valve, Helium could be rapidly substituted for the Ar:O mixture to verify system operation.

The turbo pump used was a 'clean' turbo with a diaphragm backing pump. The multiple valves in the system allowed the pressure and flow through the cavity to be controlled with precision.

The rf system: To couple the rf into the cavity a custom capacitive coupler was used which more closely matched the Q of the warm cavity. Figure 3 shows the Superfish model for the fields and a

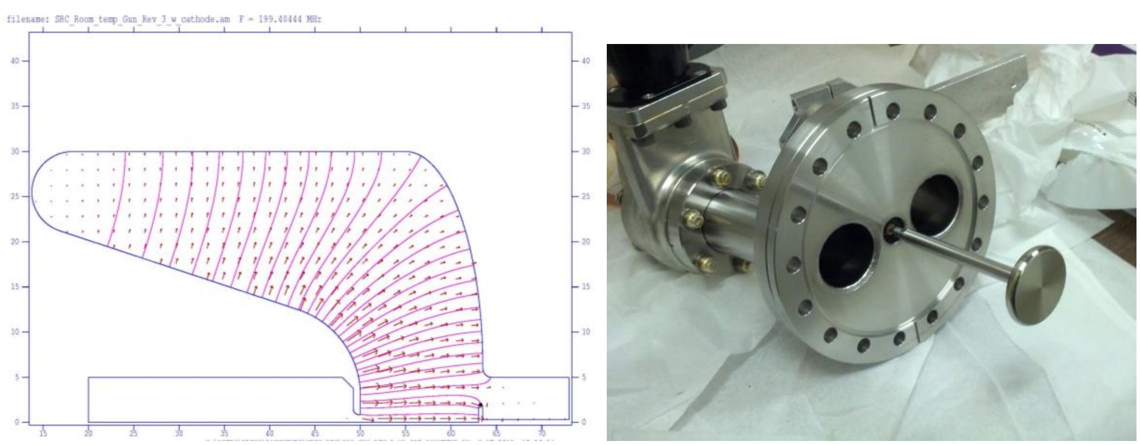

Figure 3 Plasma processing coupler

picture of the assembly outside the cavity. A directional coupler was installed in the ½" foam flex cable to the cavity to directly monitor the forward and reflected power from the system using a Bird power meter and a spectrum analyzer. The source used was a frequency synthesizer which allowed the freq of the warm cavity to be tracked. Initially a 20 kW solid state transmitter was used as the drive after conversations with the JLAB group indicated the need for more power, but after initial tests with helium we determined that we did not need the power and switched to a 100 watt ENI solid state amplifier.   This greatly simplified operation. During operation we were able to run either critically or slightly over coupled in most cases.

The spectrometer: We used an Ocean Optics 4000-EXR USB spectrometer for data acquisition with the extended bandwidth fiber bundle. The fiber was held in a fixture looking through a sapphire window on a port adjacent to the rf coupler. To improve the flux coupled to the fiber, a focusing lens was attached to the port. The detector output was digitized with 16 bit ADC.

Figure 4 Fiber on port with lens

The SpectraSuite software supplied with the spectrometer was used to collect the data. The software allowed the detector to integrate the signal for up to 10 seconds per point with a variable boxcar window which allowed the output to be smoothed. It also allows for background subtraction and detector noise subtraction. Only the background subtraction was used since the long integration times allowed the detector baseline to shift by a few 10's of counts out of 65000 fullscale.

Results

A plot of the initial Helium spectra is shown in Figure 5. The red dots correspond to the relative intensity peaks for helium from NIST emission spectra. Initially we were concerned that the relative intensities observed did not correspond well to the intensities reported by NIST[8]. After discussion with a photoemission spectroscopist though[6], it was made clear that the relative intensities measured are very dependent on the pressure, excitation state of the gas and the measurement equipment used in the experiment. The inset in Figure 5 shows the glow seen at the observation port on the coupler flange. The special coupler antenna can be seen left center and the dark spot to the right in the center is the cathode insertion hole in the cavity nosecone seen across the cavity. From previous papers[7], we knew the pressure of the gas should be between 0.01 and 1 torr, but determined the final pressure and rf power empirically to give the greatest amount of light at the observation port without breaking down the space on the backside of the coupler. Using helium we determined that higher pressures required less power to breakdown but didn't give as uniform a glow in the cavity.

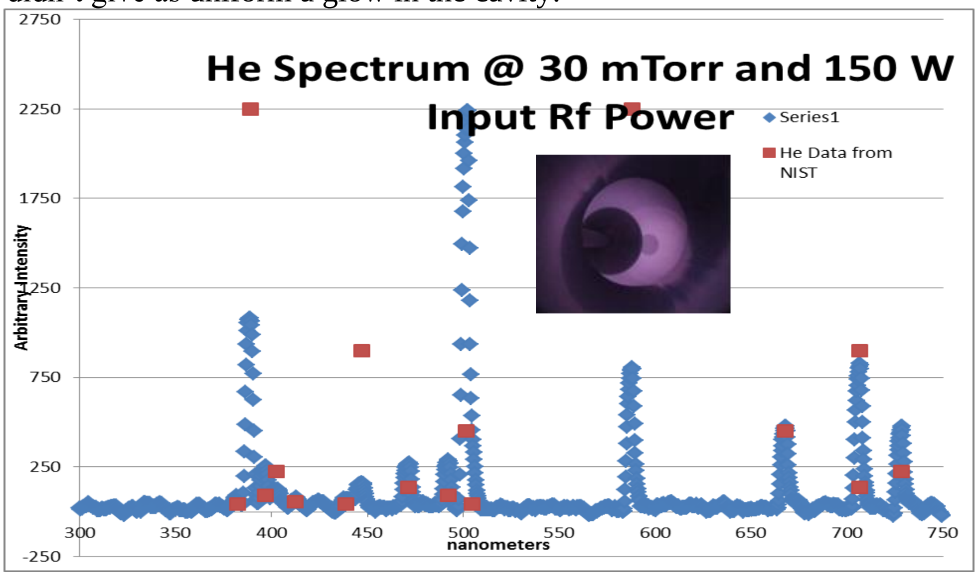

Figure 5 Initial results with Helium

After making ourselves comfortable with operation with helium, we switched to Ar:O in a 10:1 ratio. Because of the oxygen content in the gas, there was concern that the plasma could potentially damage the surface of the cavity, so special care was taken in monitoring the plasma processing of the cavity. The Ar:O doesn't radiate as nicely as the helium, so we operated at a higher pressure of 150 mT and a power of about 10 watts. The optical power was much lower than with the helium mixture and consequently required significantly more attention to detail on the spectroscopic data to maintain reasonable signal to noise ratios. Figure 6 shows the spectra of the Ar:O plasma. The relative intensity of the CO line to

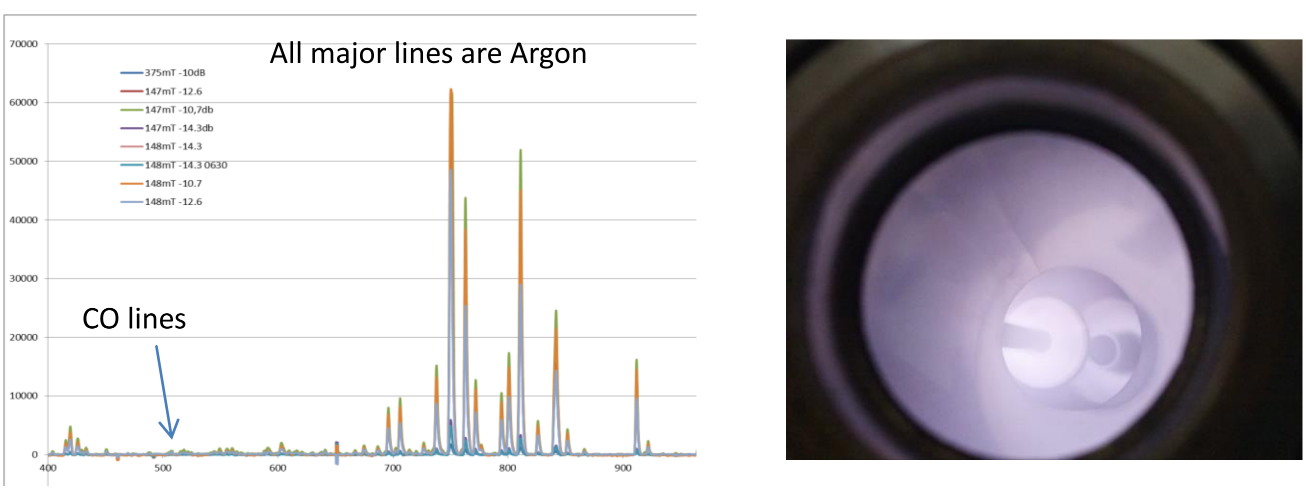

Figure 6. Spectra from Ar:O mixture

the Argon lines is striking. All major spectral lines observed were Argon. Figure 7 shows the relative intensities of the CO lines before and after processing. We did achieve a 7:4 ratio similar to the value described in the earlier paper after 36 hours of processing. A bit longer than the 10 minutes described in the paper, but our surface may have been dirtier.

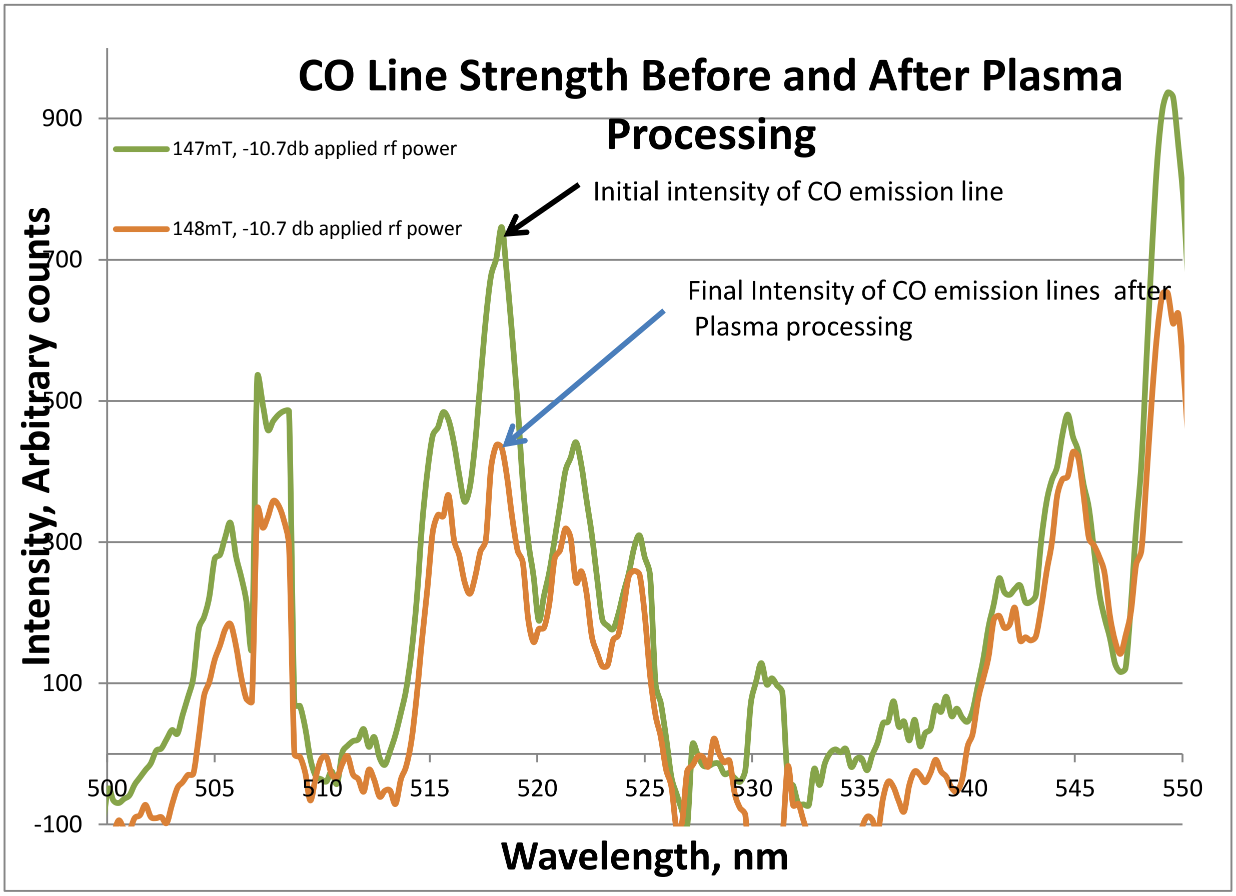

Figure 7. CO line strength before and after plasma processing

On July 18, 2013, the same cavity produced an integrated gradient of 2.8 MeV after less than 24 hours of processing. An improvement of five over the Niowave cold test.

Conclusions

Plasma processing significantly improved the field emission characteristics of our cavity. Figure 8 shows a plot of the Q0 taken at Niowave using the decay method with a matched coupler and probe along with the Q0 data taken at the Synchrotron Radiation Center using colorimetric data. Because the data is based on calorimetry, the error bars are 20%, but the fact that the point at 26 MV/m, 2.3 MeV integrated gradient, was repeatable suggests the results are real. The fact that the field was operated at 5 times the value achieved at Niowave with a Q0 similar to the low field value achieved there, argues that this means of plasma processing is beneficial to at least this cavity.

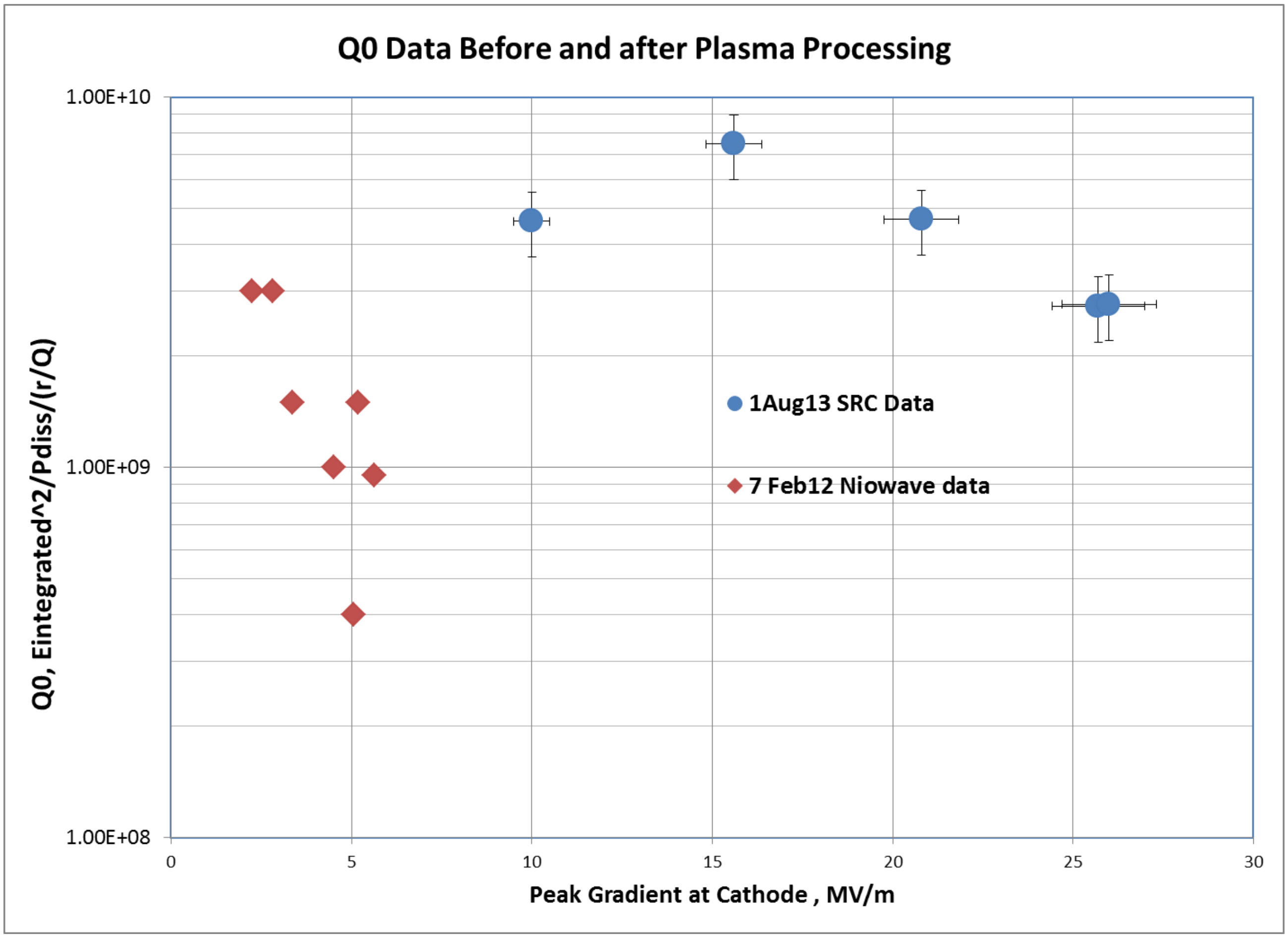

Figure 8. Q0 data from SRC and Niowave Cold Tests

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