Plasma Processing of Niobium SRF Cavities

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▪ Plasma Etching of Niobium SRF Cavities

- Reactive ion etching (Ar/Cl_2)
- Non resonant MW/RF coupling
- 100-150 micron mass removal

▪ Plasma Cleaning of Niobium SRF Cavities

- In situ or ex situ
- Room or LN_2 temperature
- Ashing (Ar/O_2) or other

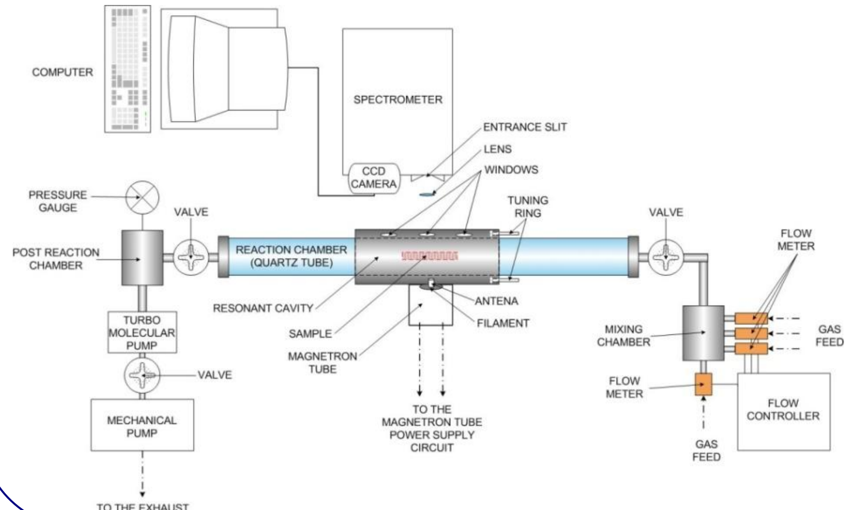
Plasma Etching
of
Niobium SRF Cavities

Outline

- Motivation
  - Low Cost
  - No wet chemistry
  - Environment and People friendly (compare to wet etching process)
  - Full control on the final surface (A variety of surfaces can be intentionally created through plasma processing, such as pure niobium pentoxide, or superconducting niobium nitride…)
- Flat Samples (Summary)
- Single Cell Cavity Setup (Present Status)
- Work Plan
- Conclusion

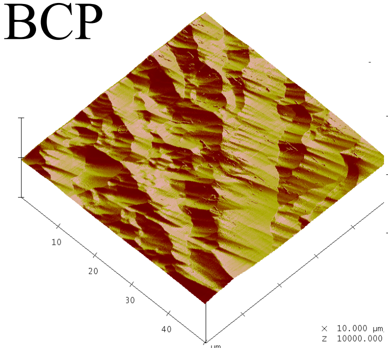
Flat Samples

Microwave Glow Discharge System

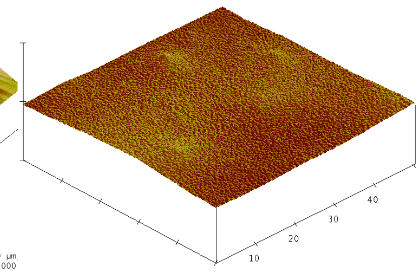


Surface Roughness

BCP



BCP + PE

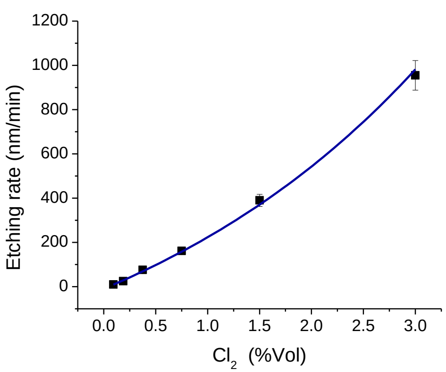


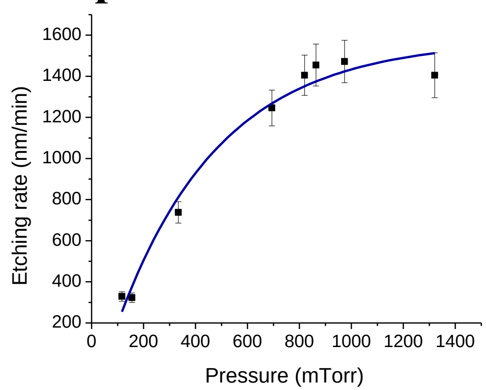
RMS (nm) 286

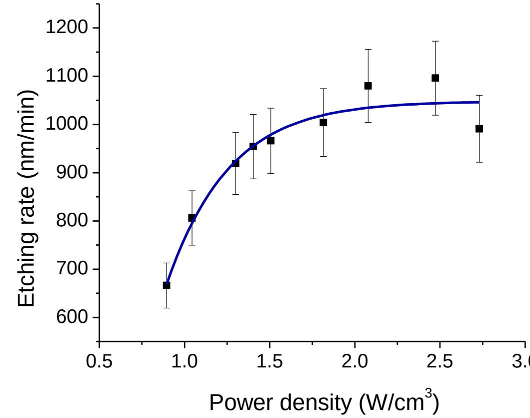
RMS (nm) 215

AFM scan (50 µm × 50 µm)

Etching Rate Dependence on Discharge Parameters



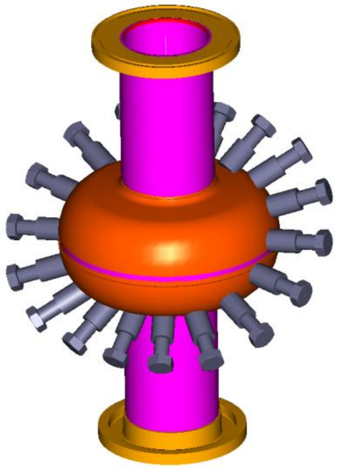




M. Rašković, S. Popović, J. Upadhyay, and L. Vušković, L. Phillips, A. M. Valente-Feliciano, "High etching rates of bulk Nb in Ar/Cl2 microwave discharge," J. Vac. Sci. Technol. A.27(2),301(2009).

Single Cell Cavity

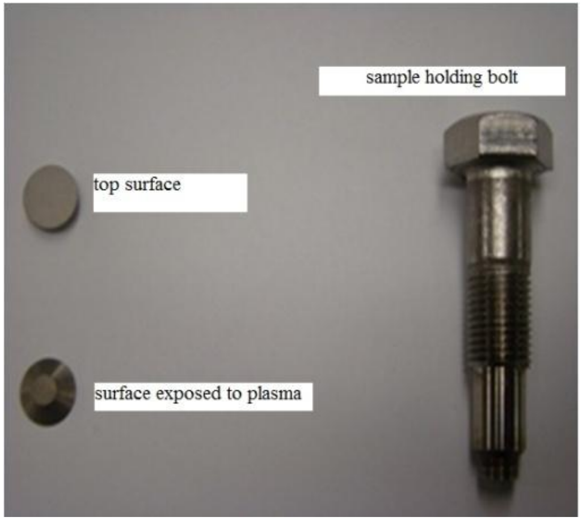
3D Model of Single Cell Cavity



Single Cell Cavity for Sample Etching

Feedthrough for Power Coupling

Sample and the Bolt for Holding Sample



Single Cell Cavity Setup

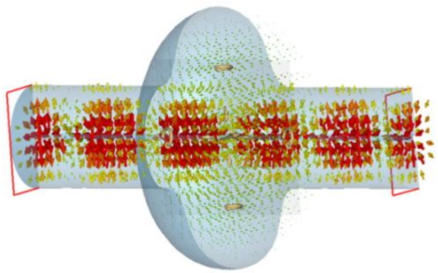
Bell-Jar System

Top Electrode Approach

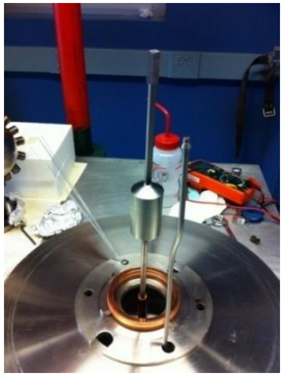
Plasma in The Cavity

Single Cell Cavity Process

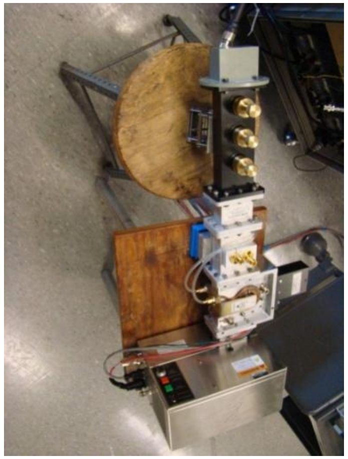
Electrode for Microwave and Radio Frequency Power Supply



MW Antenna



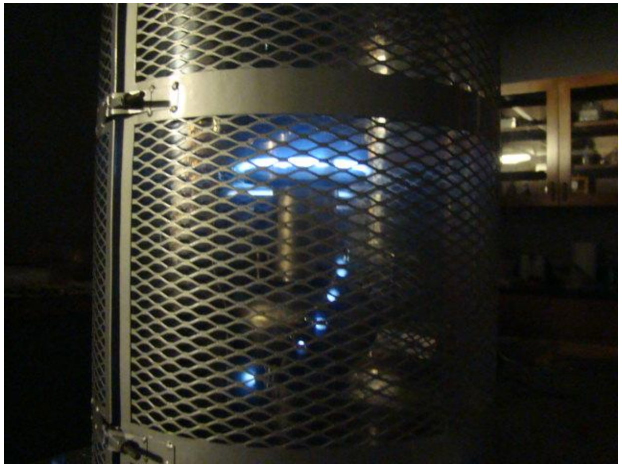
RF Electrode



Microwave and Radio Frequency Power Supply

Plasma Emanating out of Cavity

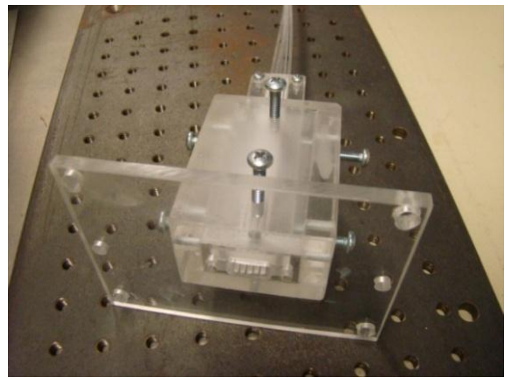
Plasma inside the Cavity



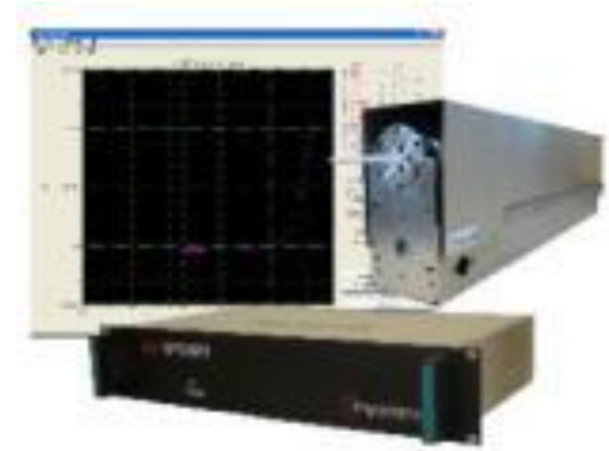
Single Cell Cavity diagnostic

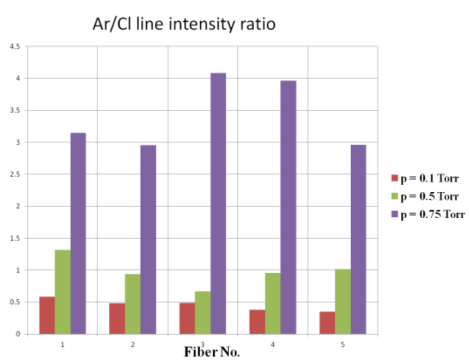
Optical Emission Spectroscopy of Cavity Plasma with Optical Fiber Assembly

Device for Simultaneous Projection of Optical Fiber on CCD

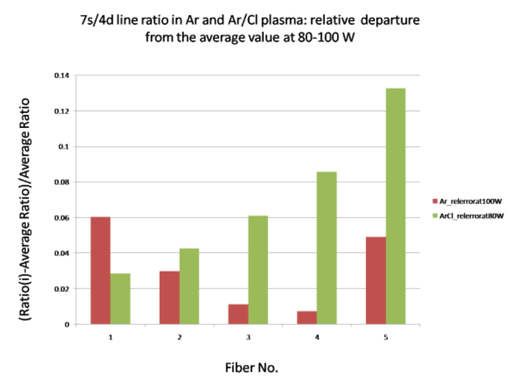


Electrical Diagnostics with Langmuir Probe





Relative intensity of Argon and Chlorine lines



7s/4d line ratio in Argon and Argon – Chlorine plasma

Work in Progress

- Choose an optimal power supply frequency between RF (10-100 MHz) and MW (2.45 GHz).

- Optimize the variables (Pressure, Power and Gas percentage) for best plasma parameters.

- See the plasma etching behavior on samples placed on actual geometry of the single cell cavity.

- Do the plasma etching of a single cell cavities and test the RF performance of the cavity.

- Trying to understand the plasma production and uniform distribution of plasma in multicell cavity and complex shape cavity.

Conclusion

- The RF performance is the single feature that remains to be compared to the "wet" process, since all other characteristics of the "dry" technology, such as etching rates, surface roughness, low cost, and non-HF feature, have been demonstrated as superior or comparable to the currently used technologies.

- Surface modifications can be done in the same process cycle with the plasma etching process.

Acknowledgement

- Financial support by JLab and DOE
- Work done in collaboration with

  Dr. Leposava Vuskovic and Dr. Svetozar Popovic , Old Dominion University, Norfolk ,Virginia

  Dr. Larry Phillips and Anne –Marie Valente -Feliciano, Jefferson Lab, Newport News , Virginia

Plasma Cleaning
of
Niobium SRF Cavities

Outline

- Motivation
- Reducing field emission.
- Suppressing of multipacting by lowering SEY.
- Cleaning the organic residue.
- Insitu Cleaning of Cavities at accelerator sites.
- Multiple Cell (5 cell) Cavity Setup (Present Status)
- Single cell cavity (Elliptical)
- Complex Shape Cavity (Spoke, Crab)
- Flat Sample
- Conclusion and Acknowledgement

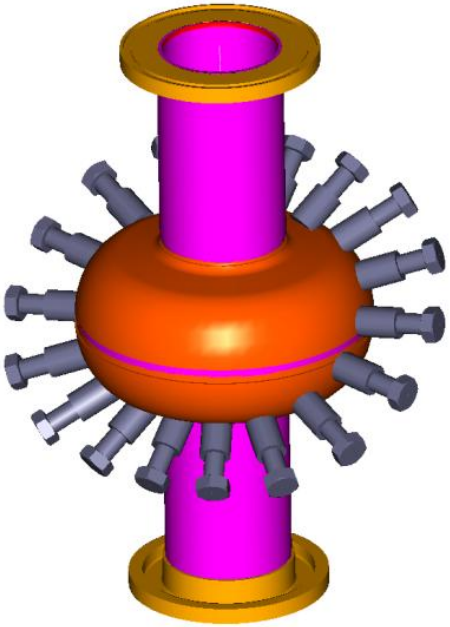
Multiple Cell Cavity

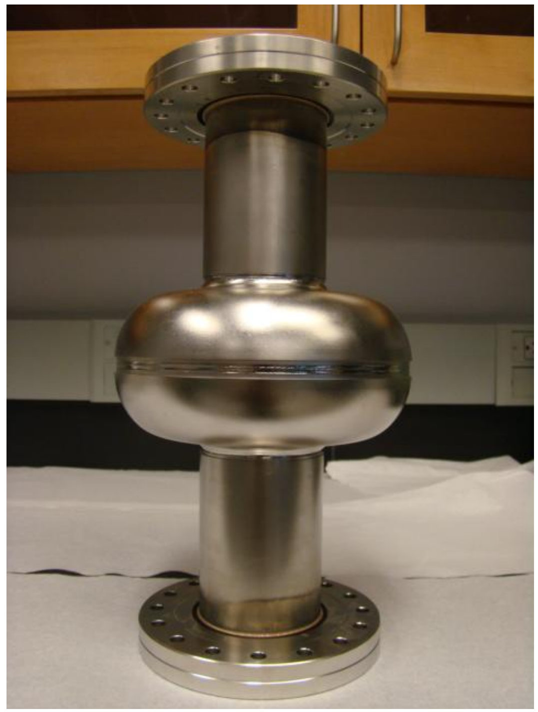
Multiple cell cavity plasma cleaning apparatus .

- **Produce different mode discharge, evaluate the pressure range where discharge can be obtained.**
- **Measure the plasma properties with optical and electrical diagnostics.**
- **See the removal of inorganic material and organic material on different position inside the cavity and correlate it with RGA.**
- **Test The RF performance of the cleaned cavity**

To produce plasma and see the plasma cleaning effect in multiple cell cavity with power connections as in cryomodule.

Single Cell Cavity

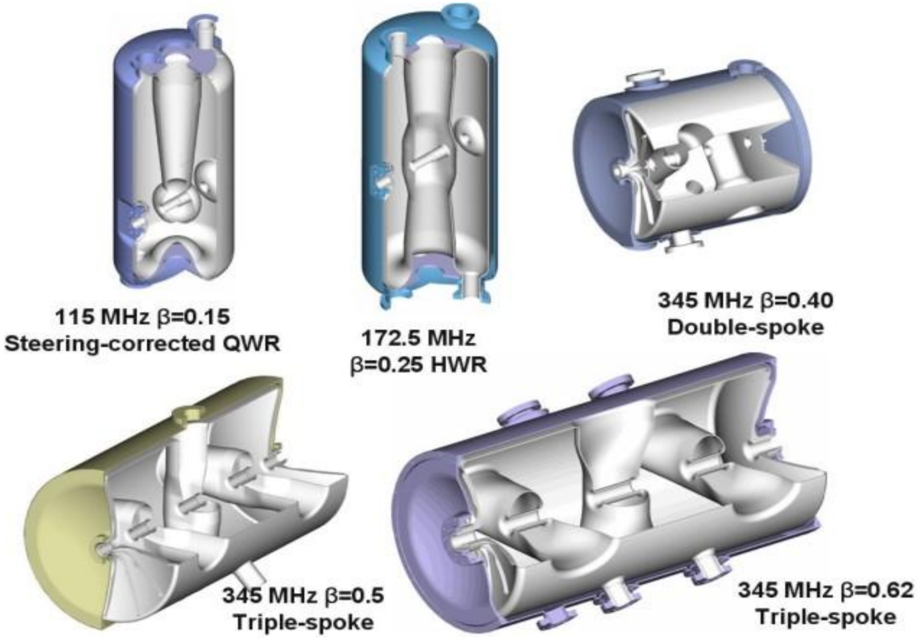




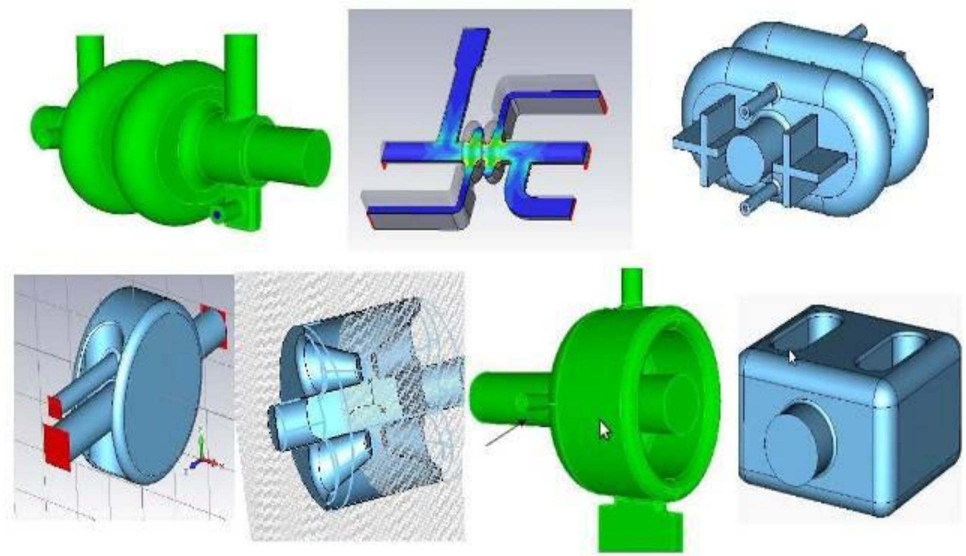
- Understand the resonance frequency plasma.
- Evaluate the plasma parameters inside the volume of the cavity .
- See the removal of inorganic material and organic material on beam tube and equator position both.
- Removal of absorbed gases

Complex Shape Cavities

Spoke cavities of different kind



Different type of crab cavity



To produce plasma and study the plasma properties in one of the complex shape cavity

Flat Sample for SEY Measurement

Nb Anodized samples

Sample plasma cleaning system

- **Removal of Organic residue**
- **Breaking the oxide layer**
- **Removal of inorganic material**
- **Removal of small size contaminants.**
- **Removal of absorbed gases**

Optimize the gas mixture , time of exposure , known impurity removal, correlation with spectroscopy and RGA

Conclusion

- The Plasma cleaning of multiple cell cavity experiment is providing the way to clean cavities inside the cryomodule as the power coupling arrangement is the same as inside the existing cryomodule in CEBAF .

- The understanding of the resonance frequency plasma production in single cell cavity and its surface effects would be interesting for future plasma cleaning experiments.

- Measuring the plasma properties at different places in the complex shape cavity would help in development of the processing technology of these cavities as they are difficult to process by other techniques.

- Flat sample would provide basic understanding of the plasma cleaning process.

Acknowledgement

- Financial support by JLab and DOE
- Work done in collaboration with

Dr. Leposava Vuskovic and Dr. Svetozar Popovic , Old Dominion University, Norfolk ,Virginia

John Mammoser and Shahid Ahmed, Jefferson Lab, Newport News , Virginia

Thank You

Surface Roughness

Surface history	Scan size (µm x µm)	Plasma etching	RMS (nm)
NP	50 x 50	Before	254
		After	231
MP	20 x 20	Before	758
		After	637
BCP	50 x 50	Before	286
		After	215
EP	50 x 50	Before	133
		After	134

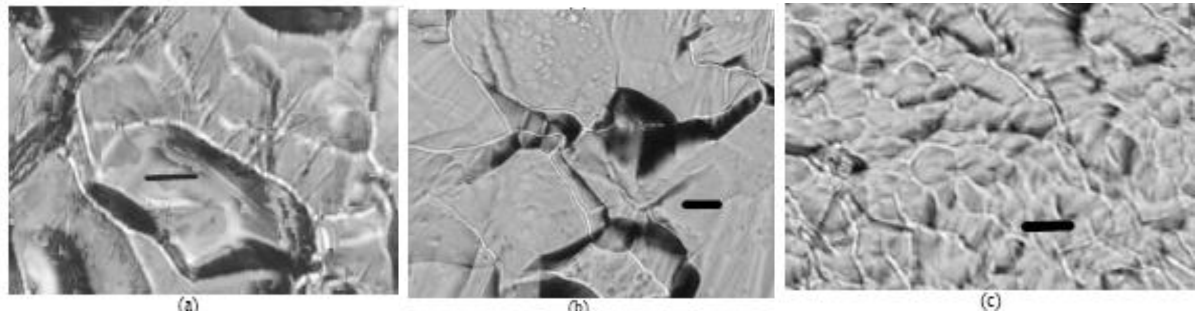
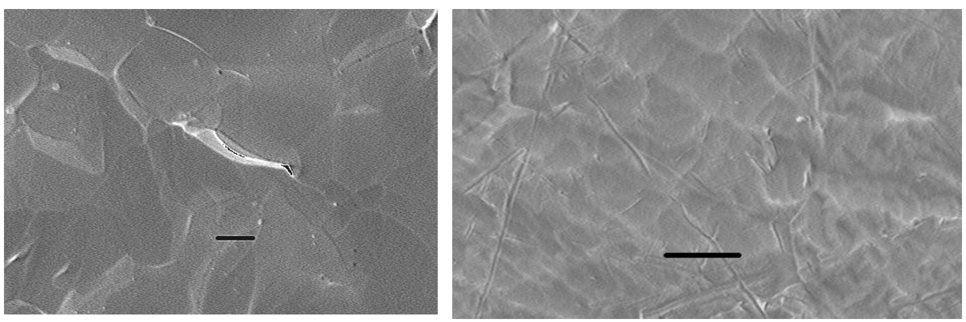


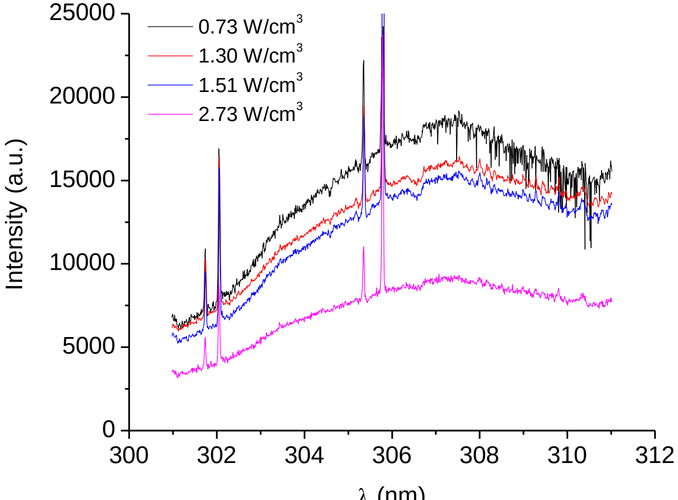
Figure 13. Comparison of surface micrographs taken with KH-3000 digital microscope with magnification 10 350: (a) an untreated sample; (b) BCP sample; (c) plasma-etched



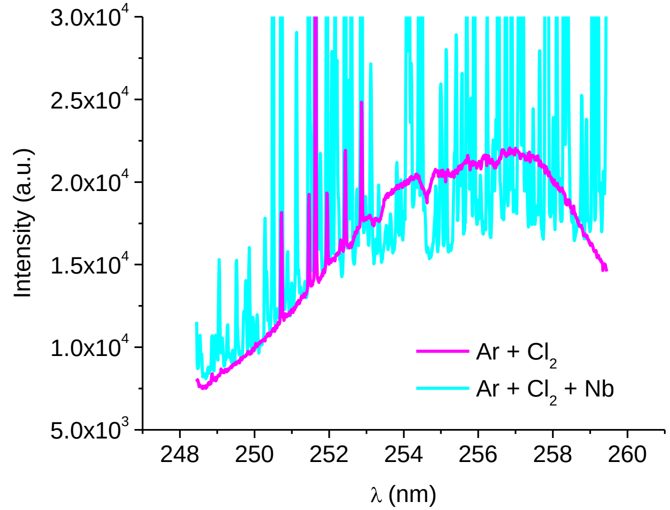
(a) (b)

Figure 15. Surface micrographs obtained with scanning electron microscope: (a) sample treated with BCP technique – magnification 500x, (b) plasma treated sample – magnification 1500x. Black lines indicate distance of 10 µm.

Optical Emission Spectroscopy



Intensity of Cl_2 continua around 308 nm as function of input power density in Ar/Cl_2 discharge.



Intensity of Cl_2 continua around 257 nm .