PLASMA ETCHING OF A SINGLE-CELL RF CAVITY – ASYMMETRIC ELECTRONEGATIVE DISCHARGE –

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Introduction

To achieve theoretically predicted values of accelerating fields, the surface of cavities must be prepared by a process that decreases surface roughness, produces surfaces with less prominent grain boundaries, and does not introduce additional impurities in the bulk of Nb.

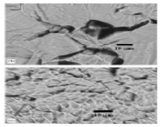
Plasma-based surface modification provides an excellent opportunity to achieve these goals.

It is a crucial technology in the development of semiconductor circuit elements, and it has been applied in preparation of superconducting devices.

However, it has not been considered so far as a viable alternative to the existing cost-intensive and environmentally unfriendly (liquid) acid-based technology.

Dry vs. wet etching processes

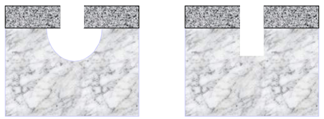
- **Plasma-assisted etch process (dry etching) is the enabling process in semiconductor industry, since it can be highly selective with respect to direction and hence indispensable in patterned removal of surface material or in removal of material from non-flat surfaces [2].**
- So far dry etching has not been seriously considered for SRF cavities.
- Wet acid etching (BCP or EP) is the process of choice in processing of SRF cavities.
- Wet etching has been all but abandoned as the fabrication process in microelectronic industry, primarily due to the isotropic material removal



Effect on Nb surface [1]

Wet process

Dry process

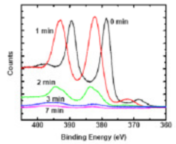


(a) (b)

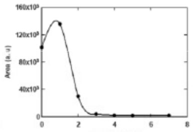
Schematic illustration of (a) isotropic action (wet) etching, and (b) anisotropic (dry) etching

Plasma etching application

- Plasma etching can be used at a wide range of pressure conditions – over 6 orders of magnitude, from millitorrs to atmospheric pressure.
- Removal under atmospheric conditions of contaminating transuranic material was demonstrated using non-thermal plasmas [3].

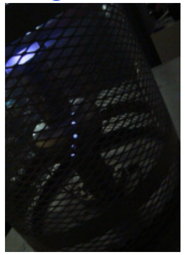


XPS spectra of uranium oxide films before and after plasma etching



Area of the U $4f_{7/2}$ peak as a function of plasma etching time

Single cell experimental set-up

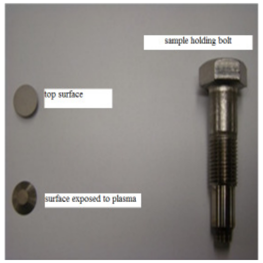


Plasma in the cavity

Bell-jar system for single cell cavity

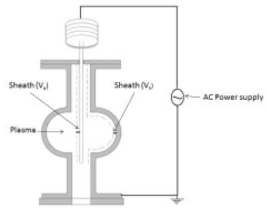
Specially designed single cell cavity

Single cell cavity for sample etching



Sample and the bolt for holding sample

Electrode design for uniform plasma



Asymmetric discharge

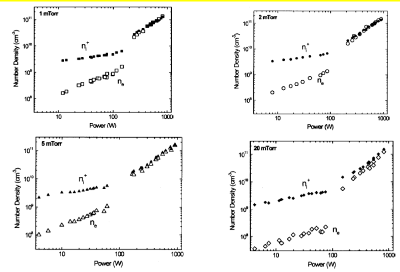
Electrode for uniform plasma

The scaling of the voltage drop in the plasma sheath with the surface area of the electrode [4].

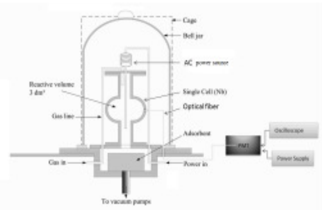
$$\frac{V_a}{V_b} = \left(\frac{A_b}{A_a}\right)^{5/2}$$

Electronegative plasma

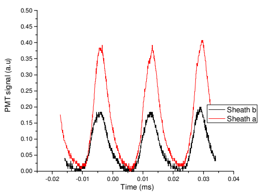
- The RF Ar-Cl_2 discharge contains large number density of negative ions at low powers (capacitive mode) [5].
- In this case plasma exists as an electronegative core ($n^+ \approx n^-$) and electropositive halo ($n^+ \approx n_e$).
- For pressures 1 and 2 mtorr the Cl_2 gas flow rate was 20sccm and for pressures 5 and 20 mtorr the Cl_2 gas flow rate was 100 sccm.



Optical fiber diagnostics



Schematic diagram of the experiment



Optical intensity at both sheaths in the discharge

Experimental approach

In view of the relatively complex technological challenges facing the development of plasma-assisted surface treatment, we have adopted a three-step approach:
- Step 1: Work with flat samples, with the objective to fulfil the requirements for etching rates, surface roughness, and to demonstrate friendly and cost-reducing aspect of the plasma-assisted process.
- Step 2: Work with a single-cell cavity to establish optimum conditions for an asymmetric electronegative discharge in cavity geometry, to demonstrate the uniformity of surface treatment, and to perform the RF performance test compatible with existing standards.
- Step 3: Work with multiple-cell cavities to demonstrate final performance of the process, to establish treatment protocol, and to define the process monitoring procedure. environmentally

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.
- The main issue is that the geometry of the inner surfaces of cavity implies that the plasma discharge has to be asymmetric, with much higher sheath voltage at the driven electrode. This is in contrast to the usual parallel-plate electrode configuration of thin film wafer treatment.
- In order for the asymmetric discharge to be effective, the lower sheath voltage at the treated surface (large area, undriven electrode) has to be at least equal or higher to the plasma floating potential at every point of the surface. When this condition is satisfied, one should expect a uniform etching and a satisfactory global RF performance of the cavity.

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References

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