Expansion of Plasma Cleaner Capability

NORTHWESTERN UNIVERSITY
MICRO/NANO FABRICATION FACILITY

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Etch Processes at NUFAB

Wet chemical etch (Si, SiO_2, metals)

RIE (Si, SiO_2, Si_3N_4, poly-Si, polyimide etc.)

DRIE (deep trenches in Si, Bosch process)

XeF_2 etch (Si)

O_2 plasma Cleaner (photoresist, polyimide)

Why Plasma Etching?

- Clean and reproducible process
- Compatible with automation
- Anisotropic etching
- Precise pattern transfer especially for Nano-scale features
- Plasma treatment only affects the near surface of a material

What is Plasma ?

Plasma is the fourth state of matter. It is an ionized gas, a gas into which sufficient energy is provided to free electrons from atoms or molecules and to allow species, ions and electrons to coexist (T_e~10^3 K, n_e~10^{9-13} cm^{-3})

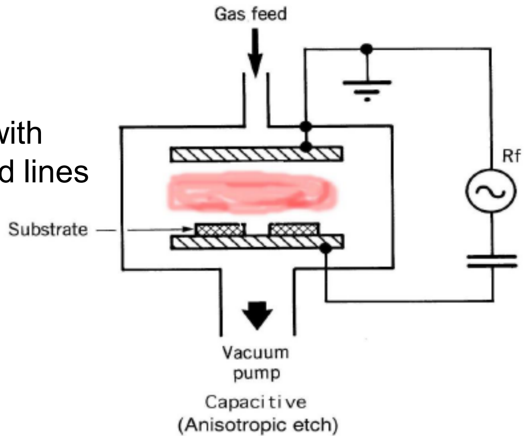
Electron (e^-)

Ions (Ar^+, Cl^+, SiF_3^+, CF_3^+)

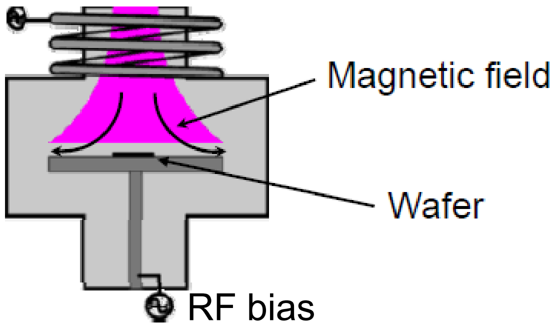
Radicals (F, Cl, O, CF_3)
Uncharged species with unpaired electron

Capacitively coupled plasma: Low density plasma $n_e \approx 10^9$ [electron/cm^3]

RF electric field
acceleration of e^-
scattering of the e^- with neutral atoms or field lines



Inductively coupled plasma: High density plasma $n_e \approx 10^{13}$[electron/cm^3]
(Independent control of ion flux and energy to the wafer, improved selectivity and etch rate)

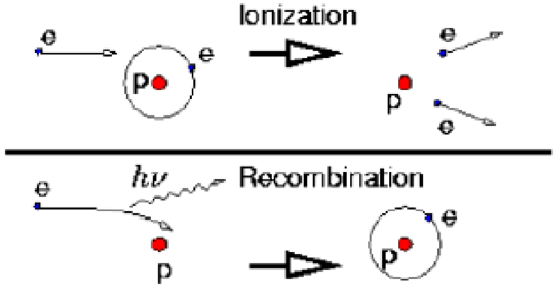


resulting ions and electrons interact with the fluctuating magnetic field to generates enough energy to ionize more atoms by collision

Plasma Chemistry

Dissociation $CF_4 + e^- \rightarrow CF_3 + F + e^-$

Ionization $Ar + e^- \rightarrow Ar^+ + 2e^-$



$Si + 4F \rightarrow SiF_4$ (gas)

Solid	Etch Gas	Etch Product
Silicon	CF_4, Cl_2, SF_6	SiF_4, $SiCl_4$, $SiCl_2$
SiO_2, SiN_x	CF_4, C_4F_8, CHF_3, SF_6	SiF_4, CO, O_2, N_2, FCN
Al	BCl_3/Cl_2	Al_2Cl_6, $AlCl_3$
Ti, TiN	Cl_2, CF_4	$TiCl_4$, TiF_4
Organic Solids	O_2, O_2/CF_4	CO, CO_2,
GaAs & III-V	Cl_2/Ar, BCl_3	Ga_2Cl_6, $AsCl_3$
Cr	Cl_2/O_2	CrO_2Cl_2

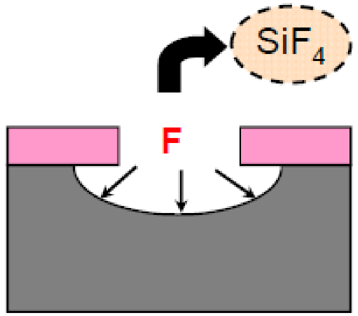
Difficult materials to etch:

Fe, Ni, Co, Au, Ag, Pt → halides not volatile
Cu → Cu_3Cl_3 is volatile above 200^C

Plasma Etching

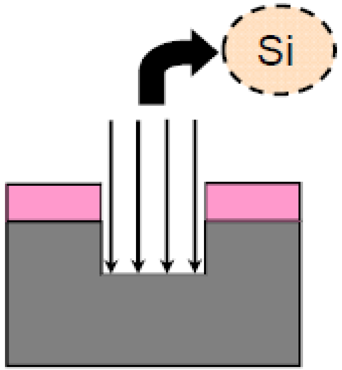
Reactive etching is an isotropic process
(very high selectivity)

$Si + 4F \rightarrow SiF_4$ (gas)



Ion etching is an anisotropic process
(lower selectivity and etch rate)

$Si + Ar^+ \rightarrow Si + Ar^+$



Reactive ion etching is an anisotropic process
(Has better selectivity and much higher etch rate)

Current Capability of Plasma Cleaner

Used in both plasma etching (PE) mode as well as reactive ion etching (RIE) mode

-Precision cleaning of optical components and molds

-Photoresist ashing & descum (removal of residual photoresist in trenches)

-Removal of organic contaminants (**chemical** reaction or physical sputtering of hydrocarbons)

-Plasma treatment: introduces polar functional groups, and induces high surface wettability (hydroxylation OH groups) (improves the ability of many photoresists to spread evenly)

-Sterilize and remove microbial contaminants on the surface (biomedical and biomaterials research applications)

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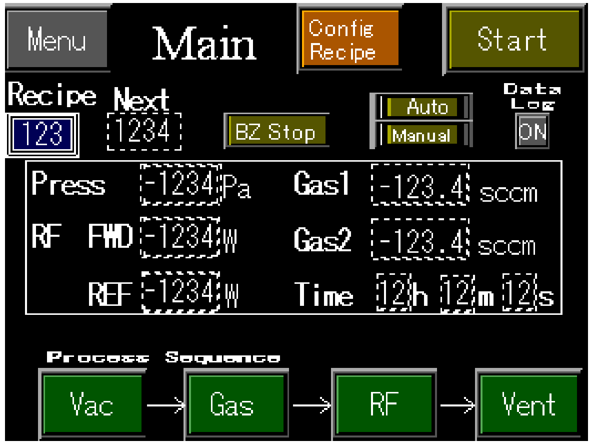
Plasma Cleaner-SAMCO PC300

Features

1. Touch Screen Interface
2. RF power 300W max, 13.56 MHz
3. Maximum substrate size: 12” x 9”
4. O_2 Plasma



Recipe 123
Next 1234
Data Log ON
Press -1234 Pa
Gas1 -123.4 sccm
RF FWD -1234 W
Gas2 -123.4 sccm
REF -1234 W
Time 12 h 12 m 12 s

Touch Screen Interface *SAMCO PC300*

Plasma Process and Applications

-O_2 plasma: removes organic contaminants by chemical reaction (highly reactive oxygen radicals) and sputtering (energetic oxygen ions).
-Ar plasma: cleans by ion bombardment and sputtering of contaminants (does not react)
-Ar/O_2 plasma: clean surfaces with a combination of sputtering (Ar) and chemical reaction (O_2).

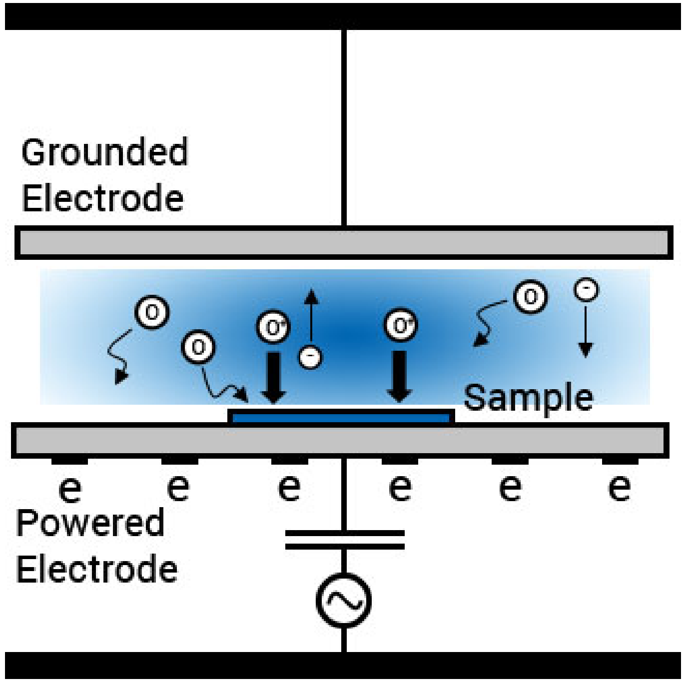
Plasma treatment can be applied to a wide variety of materials as well as complex surface geometries (Surfaces can be plasma cleaned without affecting the bulk properties of the material).

AFM cantilever tips for surface morphology and frictional force measurements
Glass and semiconductor wafers prior to subsequent deposition
Patterned Polydimethylsiloxane (PDMS) substrates for microfluidic device fabrication
Electron microscopy (EM) grids
Gold surfaces for self-assembly experiments
Fibrous polymer scaffolds for cell culturing and tissue engineering
Carbon nanotubes for use as electrodes
Quartz crystals for quartz crystal microbalance (QCM) measurements
Optics and crystals (quartz, Ge, ZnSe) for spectroscopic measurements (FTIR)
Nanoparticles plasma-treated to tune particle size and alter surface chemistry

Nitrogen Doping of Graphene: plasma can be applied to incorporate N atoms into the graphene structure to alter its electronic properties.

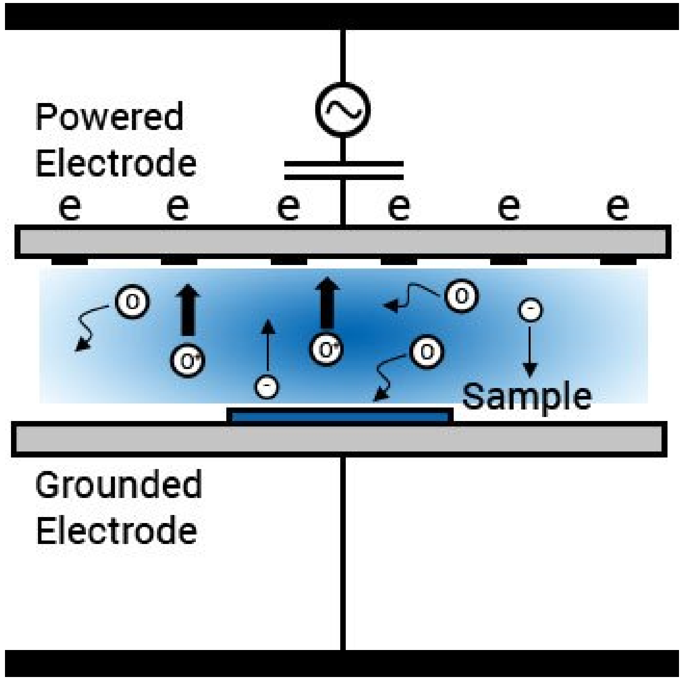
Etch Modes

Reactive Ion Etching (RIE) Mode



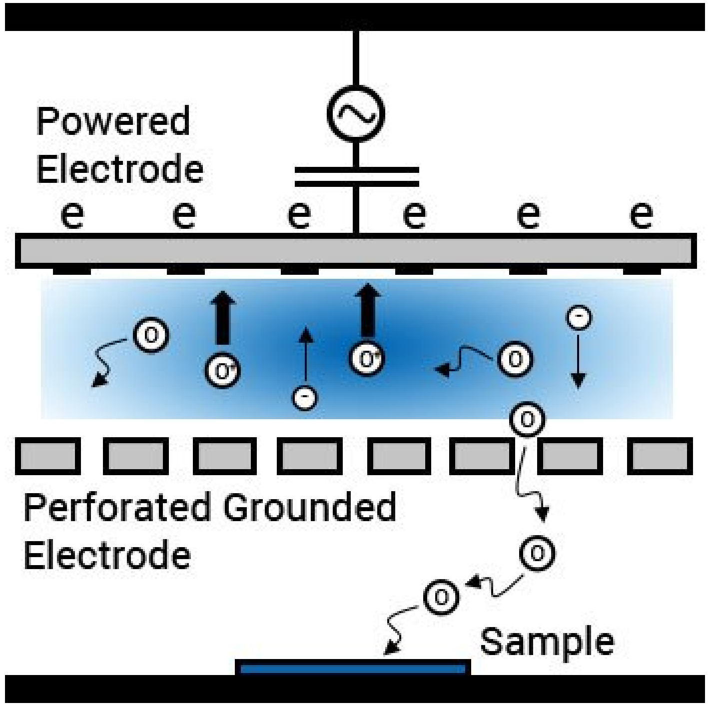
Samples are placed on the powered electrode. Ions induced by RF power directly attacks the substrate, and they will increase the etch rate.

Plasma Etching (PE) Mode



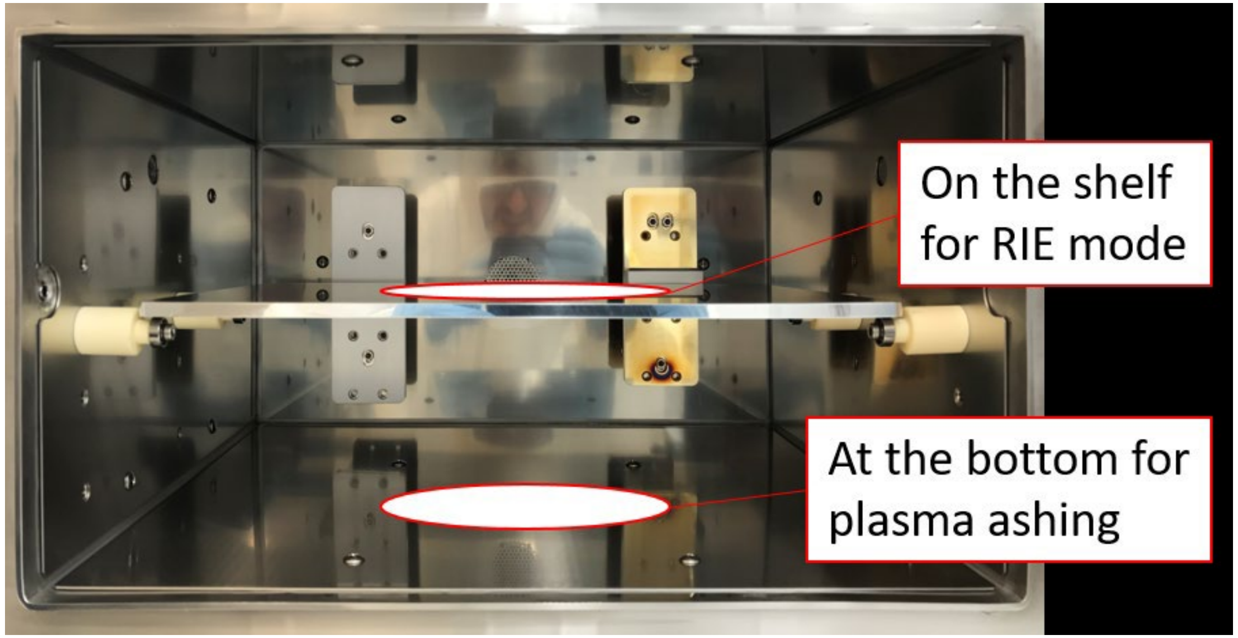
Samples are placed on grounded electrode. While ions do not attack the substrate, radicals react with the surface. This configuration eliminates the risks of plasma damage caused by ion bombardment.

Downstream Mode



A perforated electrode is placed above samples to isolate them from the plasma and minimize plasma damage.

Sample placement



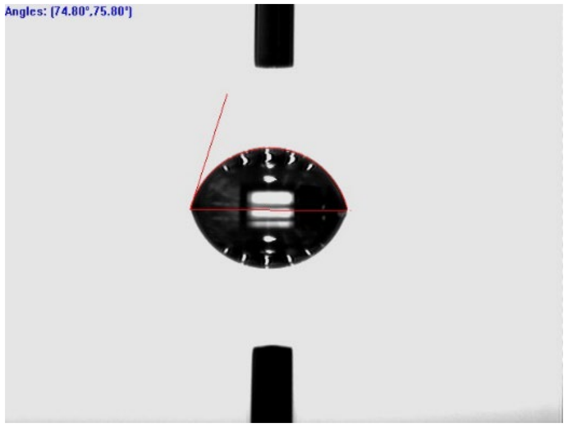
On the shelf for RIE mode

At the bottom for plasma ashing

Recipes

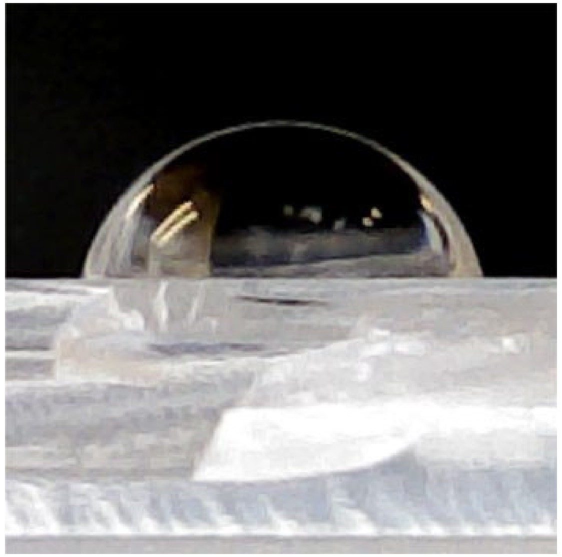
Recipe	O_2 flow (sccm)	Back Pressure (Pa)	Sample position	RF Power (W)	Usage	Rate (nm/min)
1	12	10	shelf	250	PR stripping	>150
2	50	20	bottom	100	Descum	
3	20	20	Shelf	100	Surface Treatment	
4	10	20	no sample	250	Chamber cleaning	

Surface Treatment with Plasma

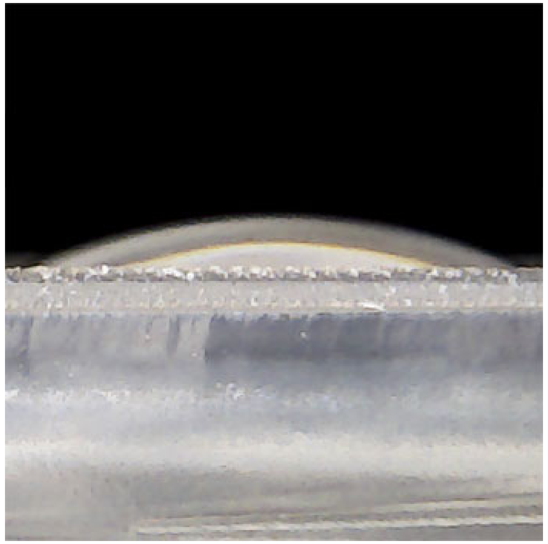


Si, Before surface treatment, 74°

Si, After surface treatment , 3°

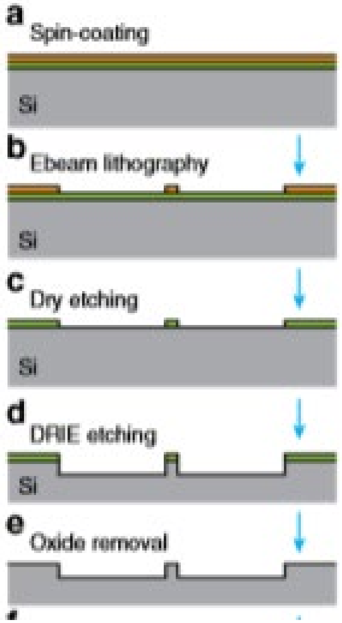


Initial PMMA, Contact Angle : 76.8°



PMMA after Plasma Surface Modification, 20.2°

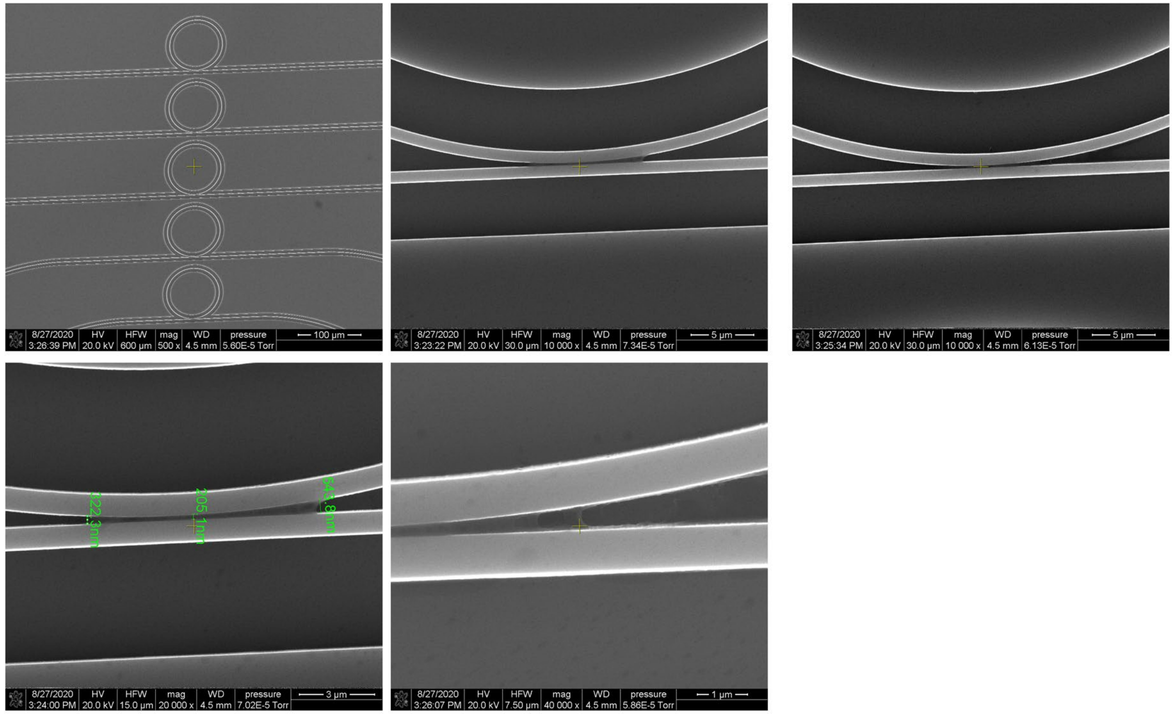
Plasma cleaning of Si mold (used for nanoimprint)



Si Mold

Si mold was treated with TFOCS ((Tridecafluoro-1,1,2,2-tetrahydrooctyl)−1-trichlorosilane) to create a hydrophobic surface.

Trichlorosilane layer and PDMS residues were removed with plasma cleaner



SEM of sample

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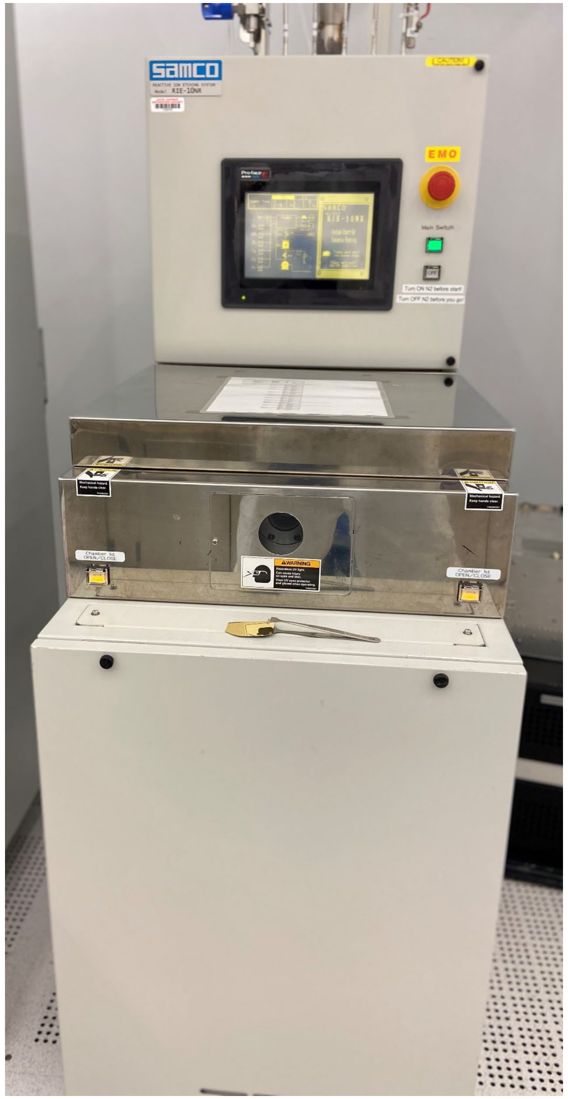
RIE-Samco



RIE 10-NR

Fluorine based chemistry, recipes for many films: Si, SiO_2, Si_3N_4, poly-Si, polyimide etc.

O_2 plasma for cleaning

Parallel plate electrodes, ideally anisotropic

Ar plasma (physical etch)

Other gases:CF_4, CH_3F, SF_6, N_2

One of the highly occupied instrument

Expanding capability of Plasma Cleaner will allow additional recipes and take some load off the RIE

The photoresist removal can be significantly enhanced by addition of small amounts of CF_4 to O_2. (Also N_2 to O_2, CF_4 to N_2)

Removing resist that have been hardened by either plasma-etching in plasmas containing halogens or by ion implantation.

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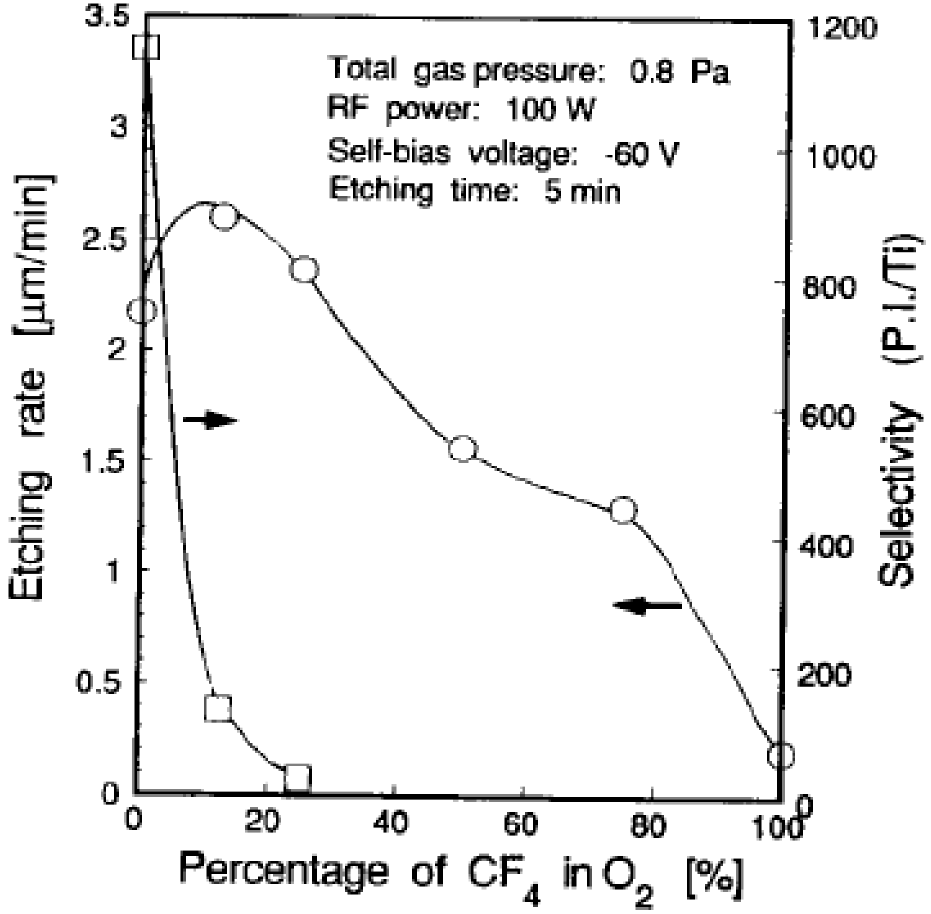
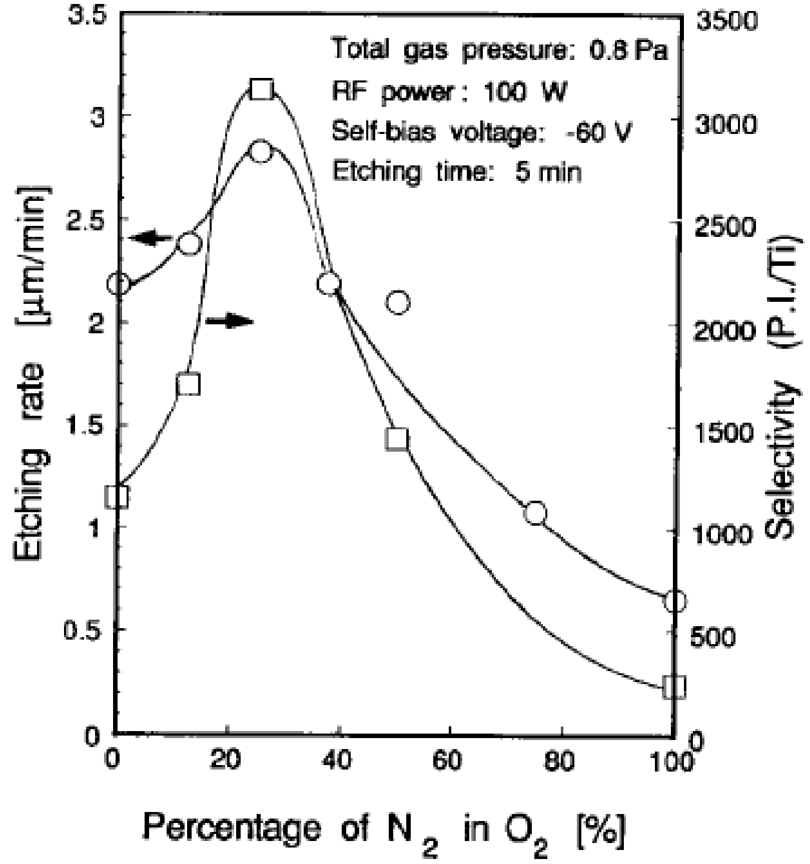
Polymer Etch comparison - expected

	Etch Rate	Selectivity
O2	1	1
CF4	1.25	0.9
N2	1.3	3

Ar		

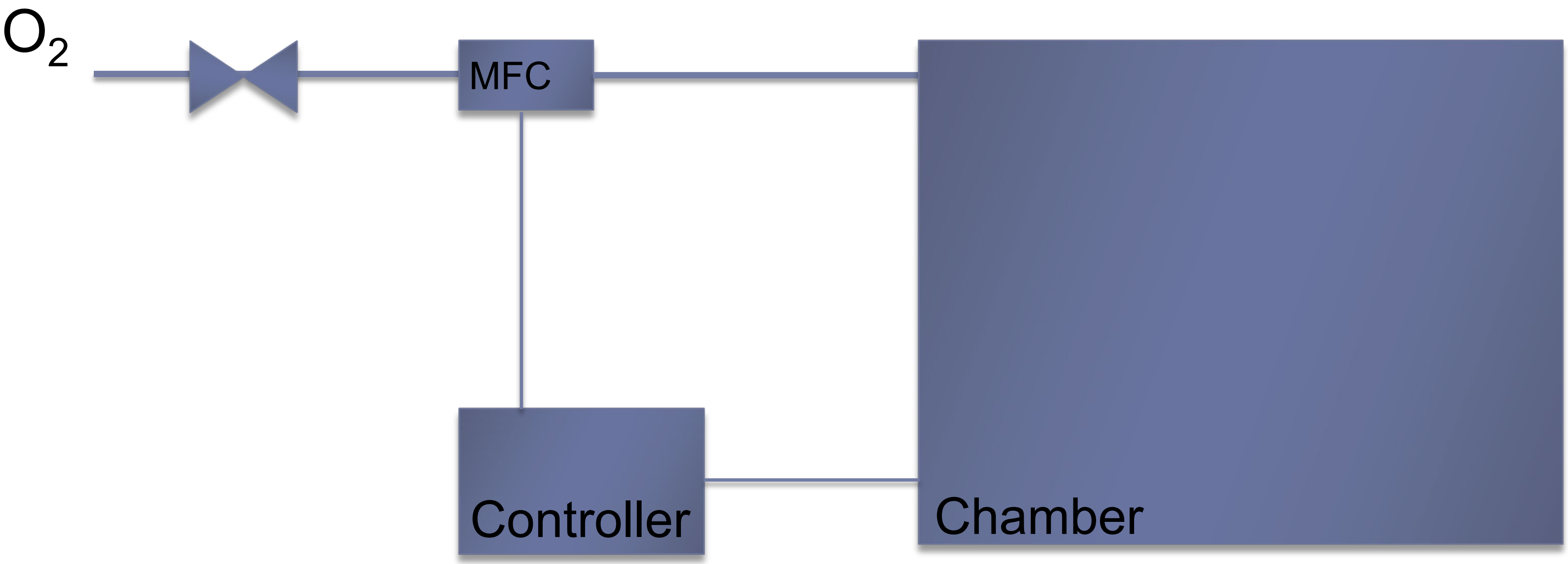
*Ar doesn’t have significant affect on etching polymers. It will be useful for other materials such as Ti, Cr.





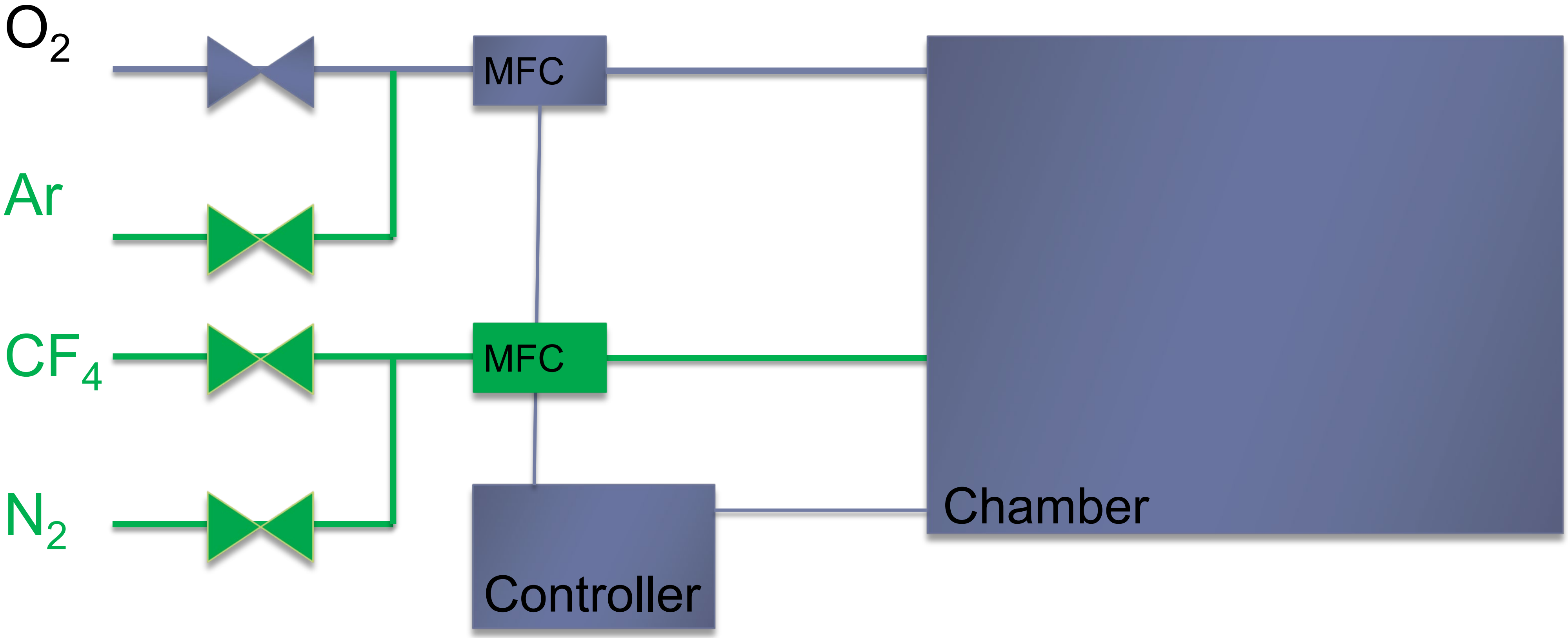
F. Shimokawa, A. Furuya and S. Matsui, "Fast and extremely selective polyimide etching with a magnetically controlled reactive ion etching system," *[1991] Proceedings. IEEE Micro Electro Mechanical Systems*, Nara, Japan, 1991, pp. 192-197

Current configuration



NEW configuration

No additional training will be required for current users



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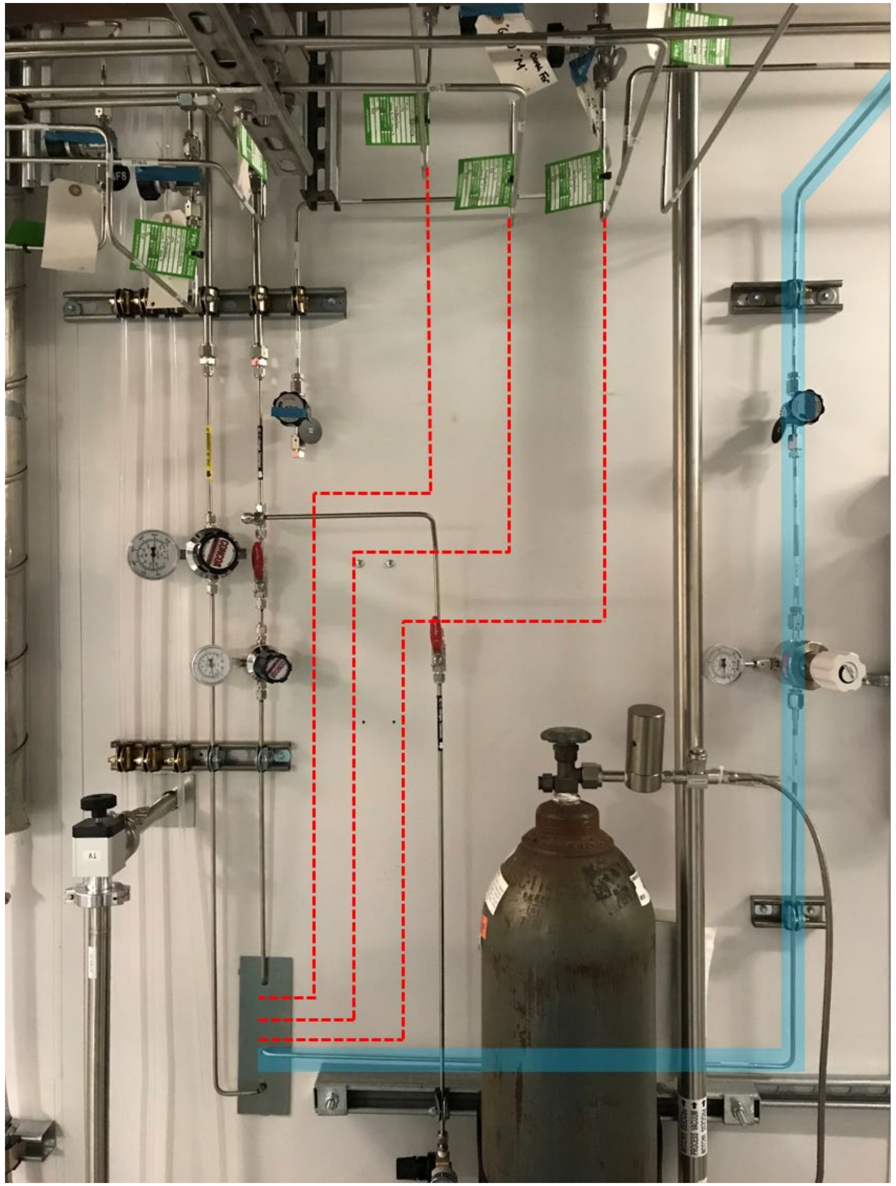
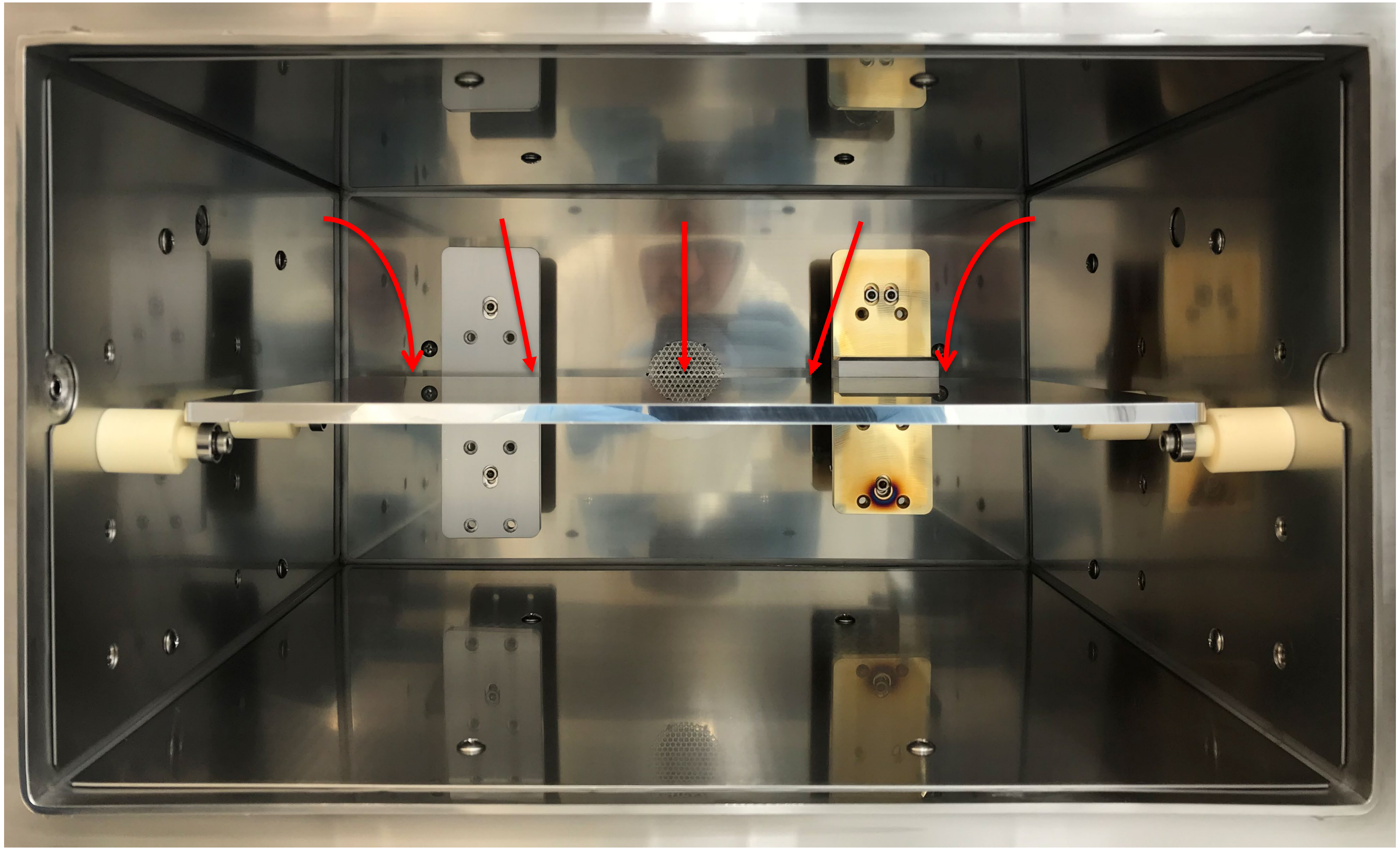


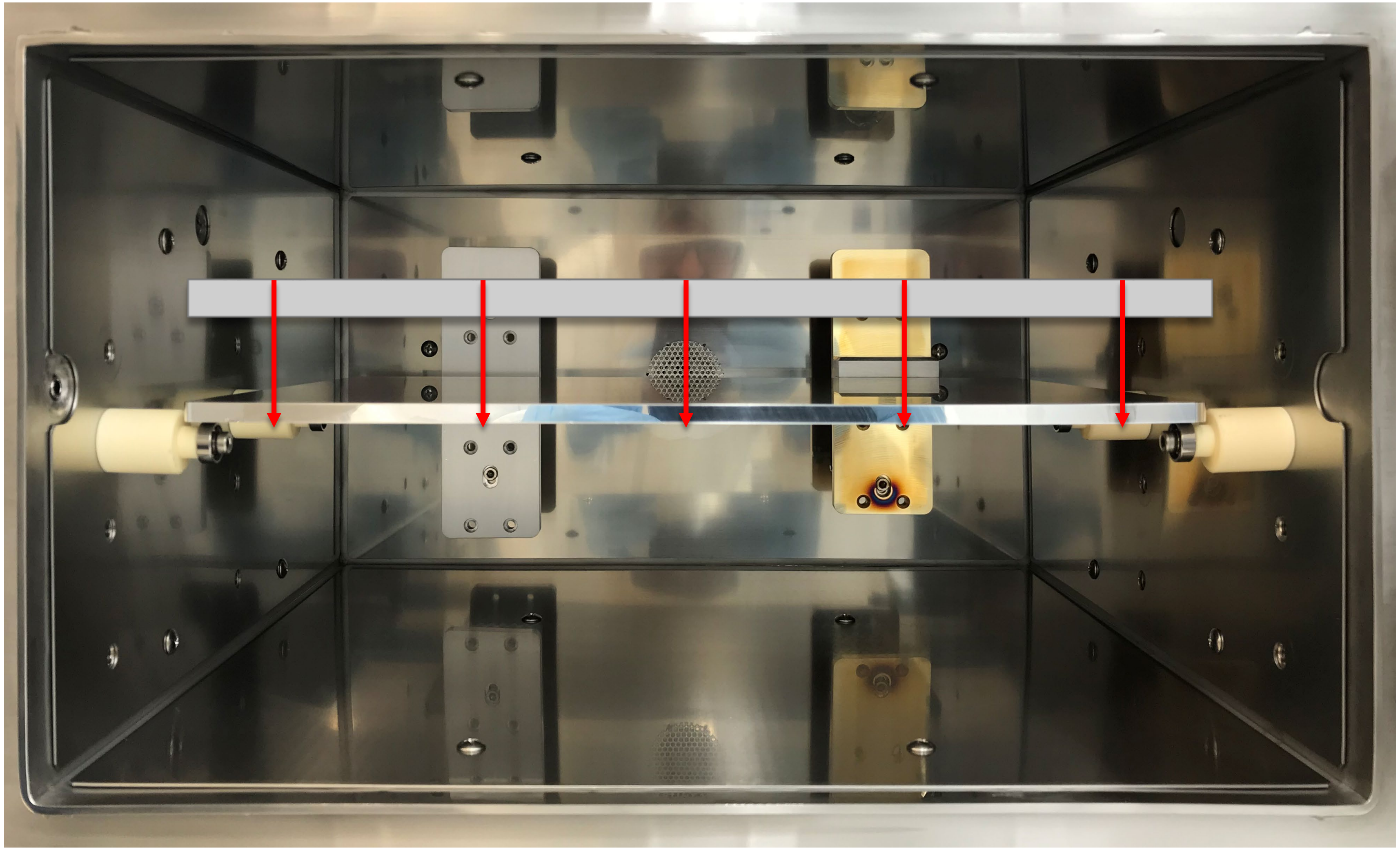
🟦 Existing O_2 line

- - - - Proposed lines

Extra shelf



Extra shelf



Thank You

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