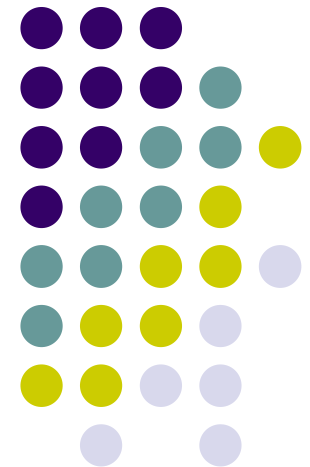
Effects of VUV Radiation and Diffusion of O_2 in p-SiOCH low-*k* films



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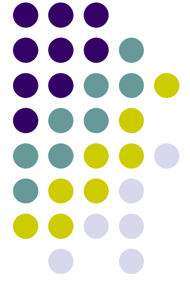
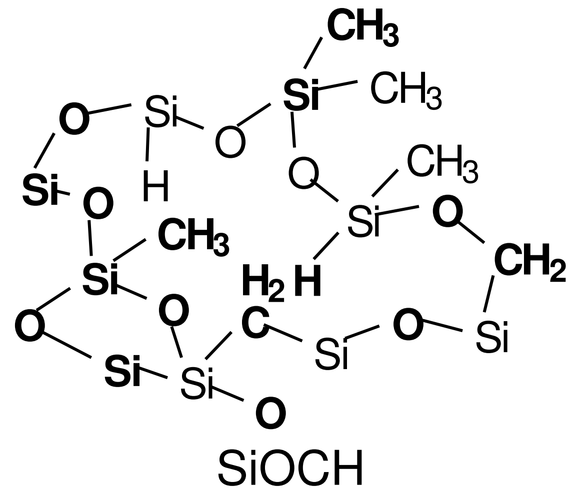
Oct. 18th, 2010

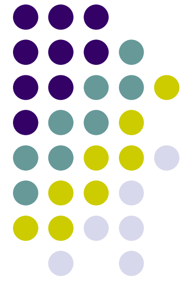


Porous SiOCH



- Many studies in the advancement of interconnect technology has been focused on the continuous lowering of the dielectric constant for dielectric materials.
  - Methylated species –SiOCH
  - Introduction of porosity to increase free volume
- The material is very susceptable to damage from plasma processing.
  - Changes in film chemistry
  - Water absorption
  - Increase in dielectric constant

Introduction



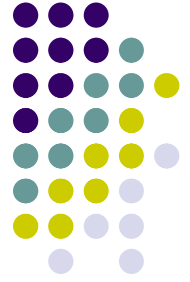
Goals

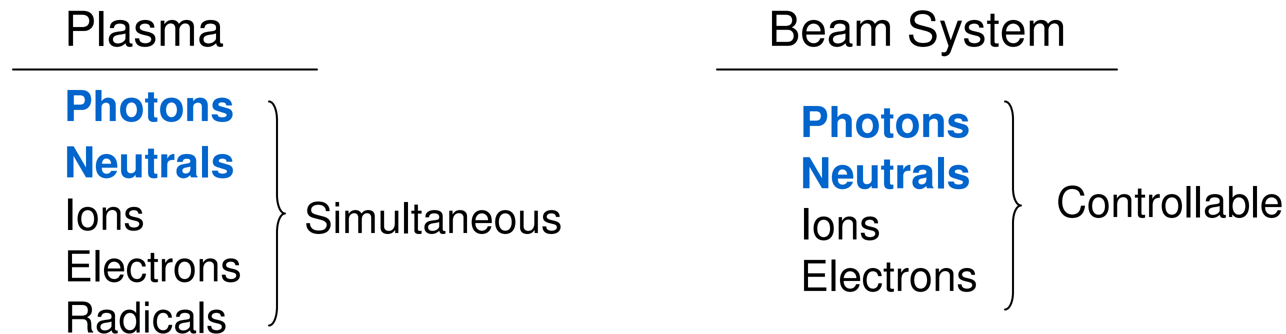
- **Use of a beam system setup to understand the damage effects of p-SiOCH materials that occur during plasma treatment.**
- **Analyze the damage mechanisms of individual species generated from a typical plasma discharge.**

Objectives

- **Show that damage from beam system exposures are comparable to plasma-induced damage.**
- **The wavelength of vacuum ultraviolet (VUV) photons is an important processing parameter.**
- **Sample diffusivity in p-SiOCH films can potentially have a large effect on damage rate.**

Plasma vs. Beam System

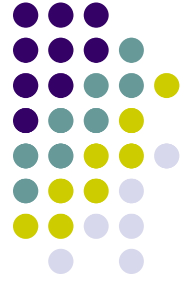




- The beam system allows for analysis of individual plasma components in a decoupled environment.
  - Effect of VUV photons and O_2 molecules.

- Exposures are compared in both systems to identify key contributors to plasma-induced damage and examine damage mechanisms.

Introduction



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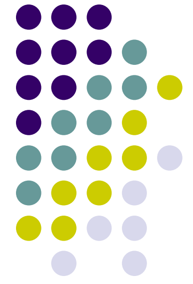


Vacuum Beam System Setup

Side View

O$_2$ inlet

VUV Source

p-SiOCH

Turbo Pump

Flux = 1.3×10^{14} photons/(cm^2 s)

Xe lamp (λ = 147 nm)

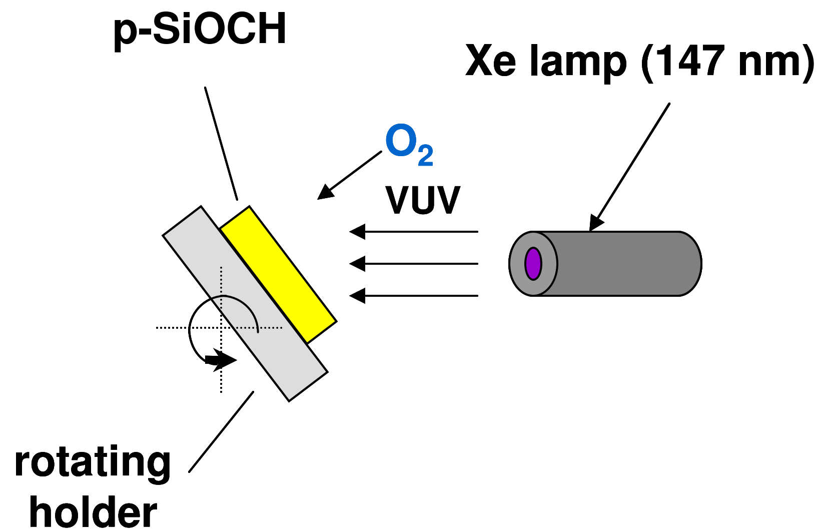
O$_2$ pressure: 10^{-5} torr

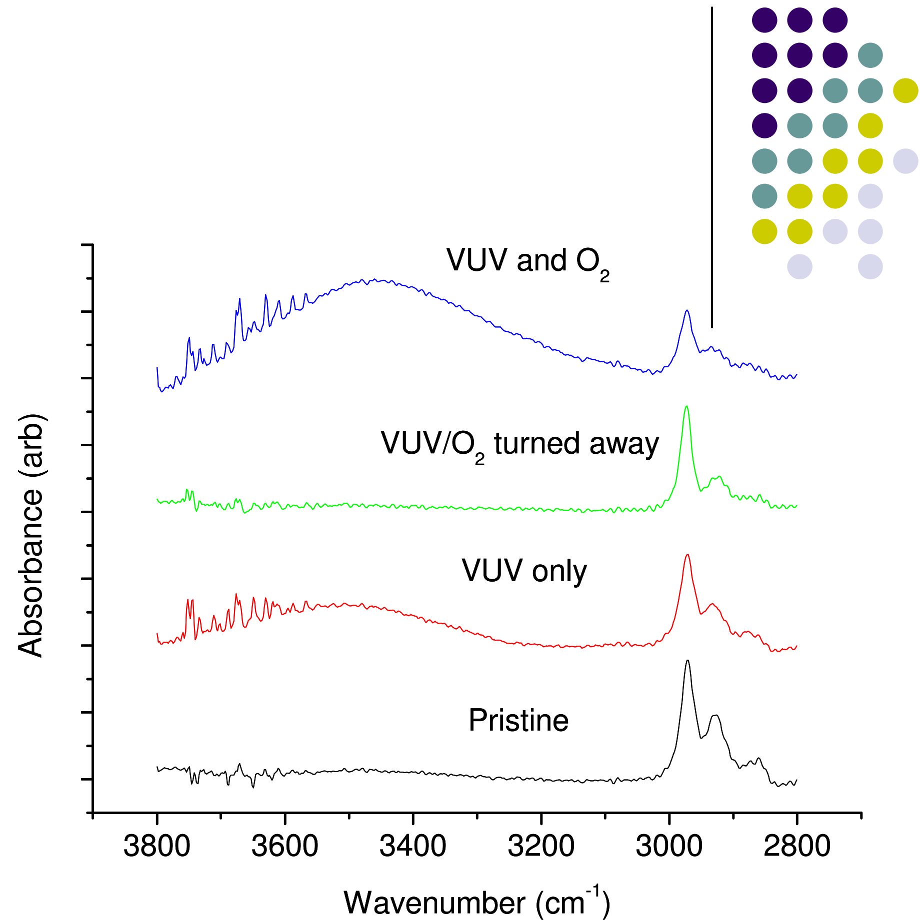
Base Pressure: 8×10^{-8} torr

Sample Temp.: 25°C

Material	k Value	Diffusivity (μ m^2-min^{-1})
porous-ULK	2.54	1500
dense-ULK	2.55	250

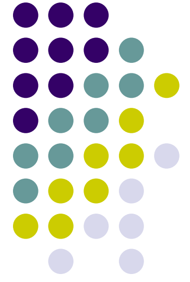
Past Studies





- SiOH/H_2O growth and methyl loss seen in porous-ULK SiOCH samples treated with VUV radiation from a VUV lamp.
- Simultaneous exposure with VUV/O_2 increases level of damage.
  - Synergistic mechanism for VUV photons/O_2 molecules in the damage of p-SiOCH materials.

J. Lee and D.B. Graves, J. Phys. D 43, 425201 (2010)



Inductively-Coupled Plasma System

Top-Down View

Ion Composition ~ Products

To Ion Mass Spec.

Ion Flux

Ion Current Probe

To Roughing Pump

Total VUV Flux

VUV Spec.

Film Sample ~1 cm^2

H_2O In

H_2O Out

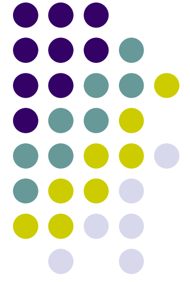
Load-Lock Port

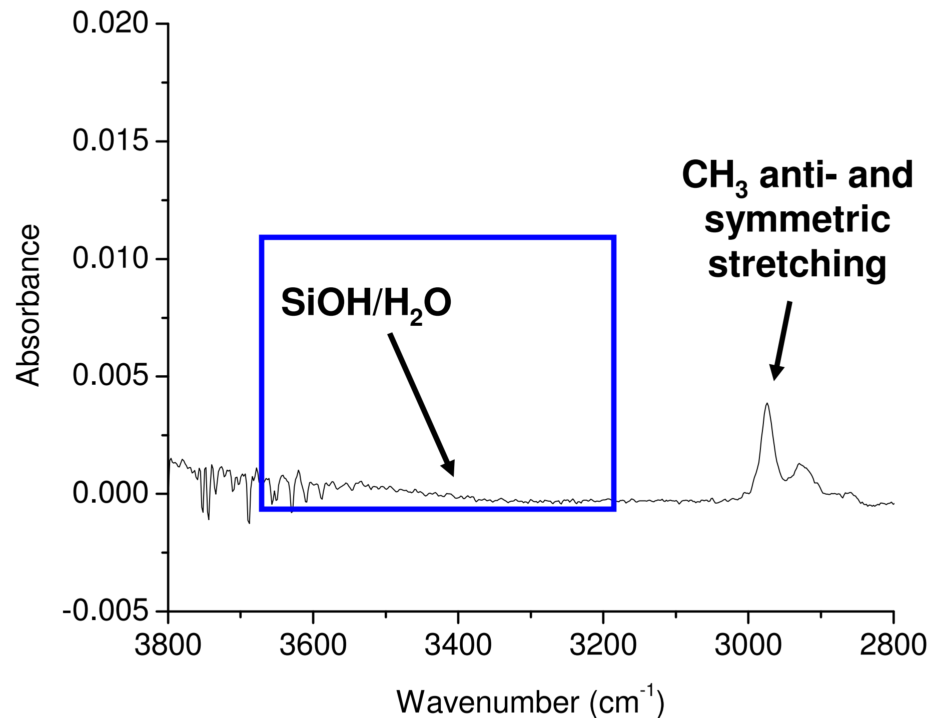
Optical Emission

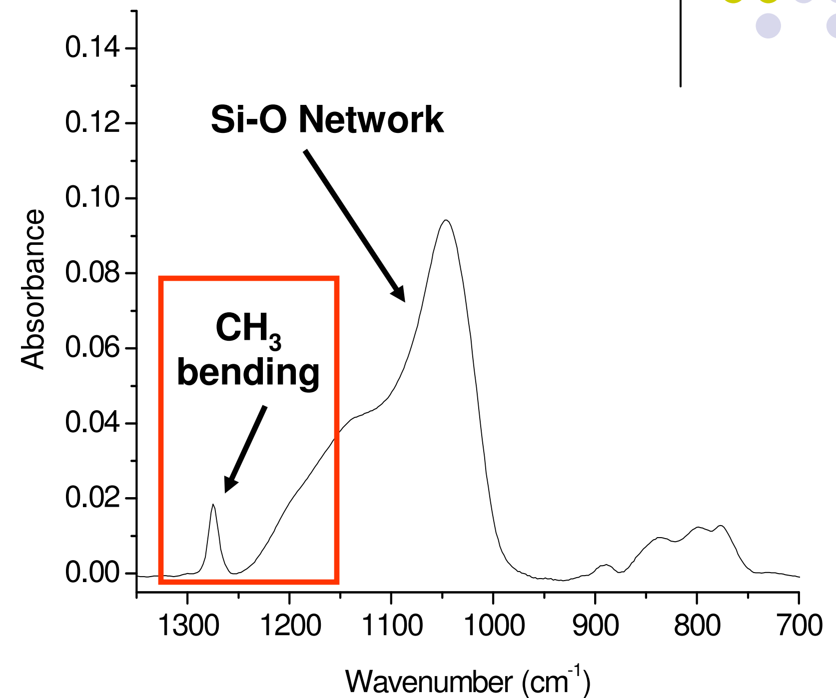
Langmuir Probe: n_e, T_e, Φ_p

- Plasma conditions:
  - 70 W Power, low energy ions (~16 eV)
  - 10 mTorr of Ar/O_2
  - ~10^{10} cm^{-3} plasma density

FTIR Spectrum of p-SiOCH

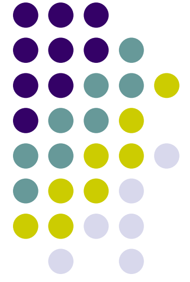


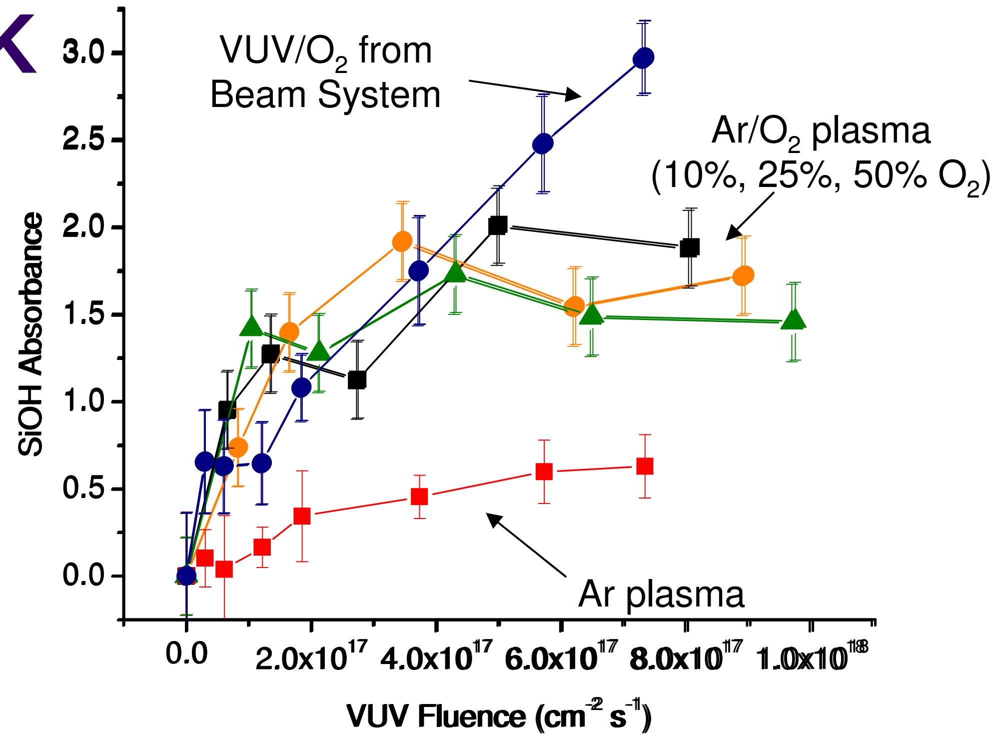




- *Ex-situ* Fourier Transform Infrared Spectroscopy (FTIR) used to identify chemical change.
- Indicators of chemical damage to p-SiOCH:
  - Drops in the methyl bending peak (~1270 cm^{-1})
  - Increases in the SiOH/H_2O broad peak (3800-3000 cm^{-1})

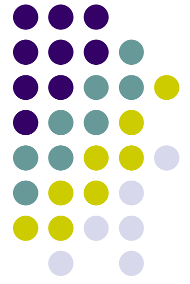
VUV/O_2 Effects in Plasma/Beam System in porous-ULK

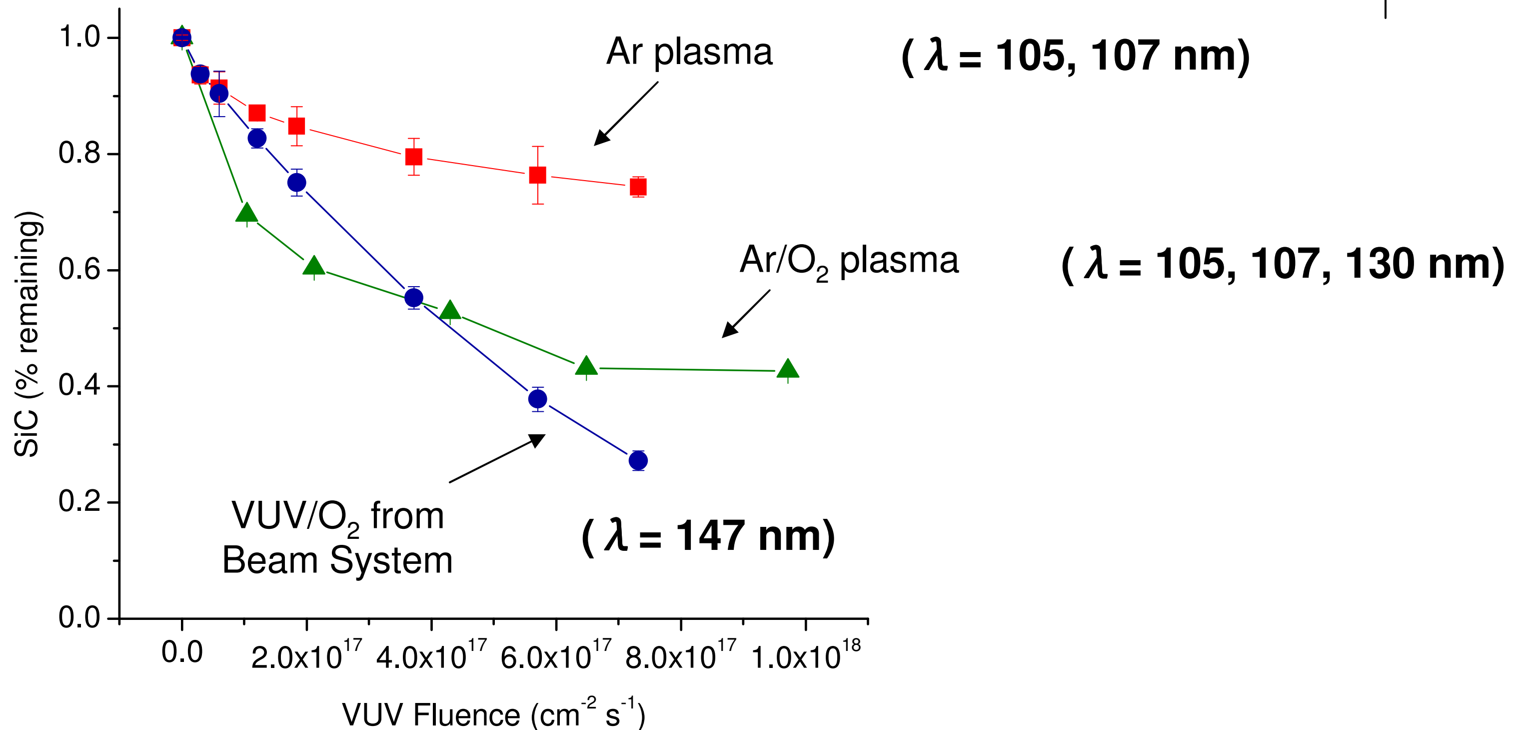




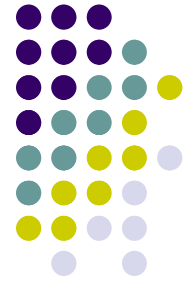
- Comparison of Ar/O_2 plasma exposures with beam system exposures show similar results.
  - While O radicals cannot be excluded, VUV/O_2 appears to be the major contributor to plasma-induced damage.

Saturation of Methyl Loss Suggest Damage Limitation





- Methyl loss from plasma exposures appears to saturate after a certain fluence while methyl loss does not reach saturation for the beam system.
  - May be due to the wavelength of the VUV photons.



Wavelength of VUV Photons Determine Damage Depth

Ar plasma
O_2 plasma
VUV source

penetration depth (nm)
10000
1000
100
10
1
100 110 120 130 140 150
Wavelength (nm)

porous-ULK

Film thickness: 220 nm

Ar plasma
modified layer
Undamaged layer

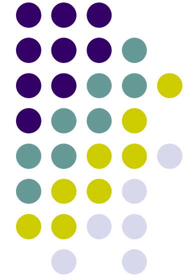
O_2 plasma
modified layer
Undamaged

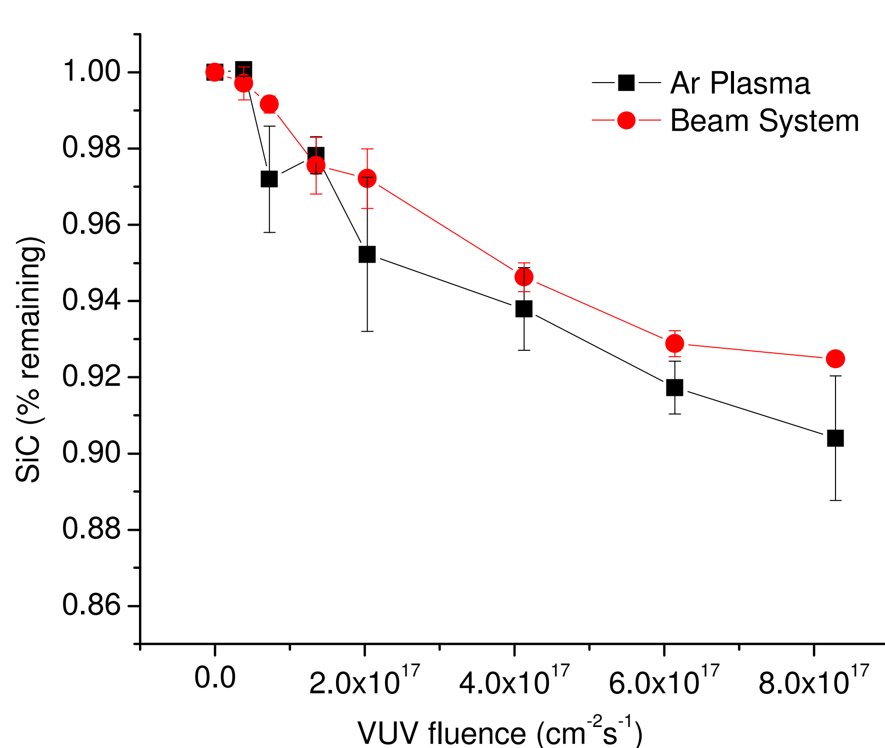
Beam System
modified layer

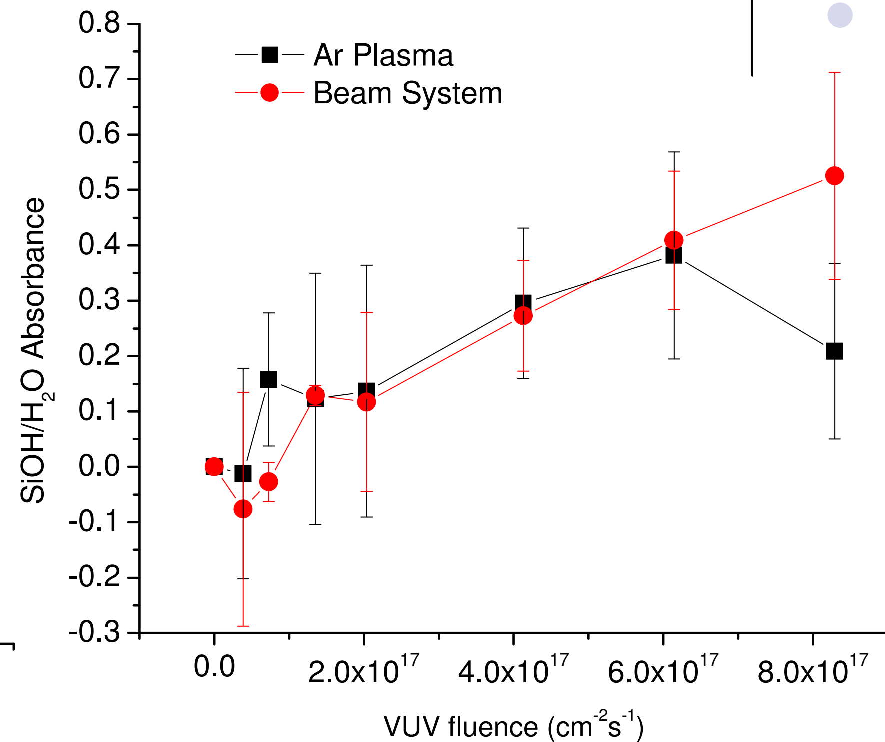
- The wavelength of VUV photons in each exposure can be seen to have very different penetration depths.
- Penetration depth of VUV photons through the α-SiO_2 modified layer is an important factor in plasma processing for porous-ULK.

Graph from J.R. Woodworth *et al.*, JVST A 19, 45 (2006)

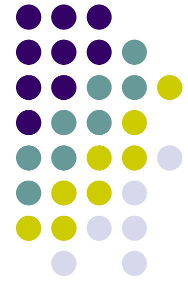
VUV/O_2 Effects in Plasma/Beam System in dense-ULK





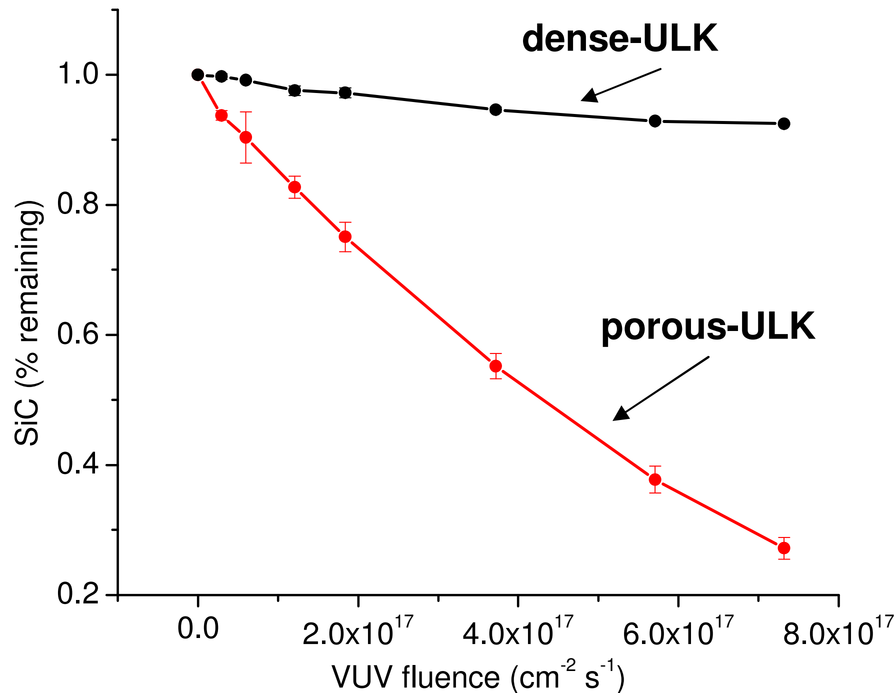


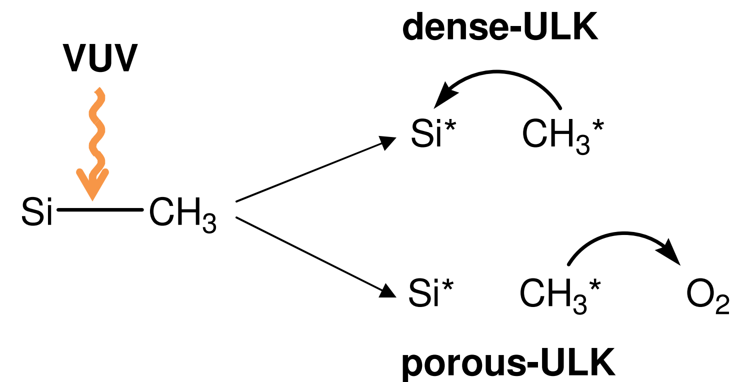
- Using dense-ULK, which has lower diffusivity, the damage profile was seen to be similar in both Ar plasma and beam system exposures.
- Suggests that the damage is being limited by diffusion of oxygen.



Effect of a Lower O_2 Diffusivity on Damage Rate

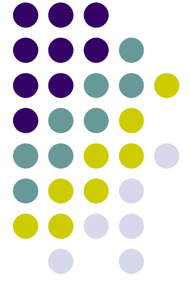
Comparison of exposures in the beam system





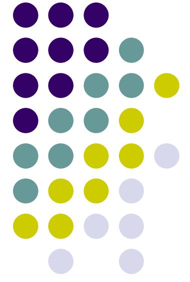
- Methyl loss in dense-ULK occurs at a much slower rate than with porous-ULK.
- Damage to porous-ULK is limited by photon penetration depth, whereas damage to dense-ULK is limited by oxygen diffusion.

Summary



- Damage from beam system exposures has been shown to be comparable to plasma-induced damage for p-SiOCH materials.
- VUV photons/O_2 molecules appear to be the major cause for plasma-induced damage.
- The damage to porous-ULK and dense-ULK is limited by different factors.
  - Porous-ULK - Penetration depth of VUV photons.
  - Dense-ULK - Oxygen diffusion.
- The wavelength of VUV photons used in plasma treatment and the diffusivity of the material are important parameters to consider in the production and treatment of p-SiOCH related low-*k* materials.

Acknowledgements



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