Diamond Window Upgrade for in Air Experiments at MEC

Jared Gladfelter[1]

1 Engineering department, Colorado State University, Fort Collins, CA

2 SLAC National Accelerator Laboratory, Menlo Park, CA

SLAC NATIONAL ACCELERATOR LABORATORY · U.S. DEPARTMENT OF ENERGY · Stanford University

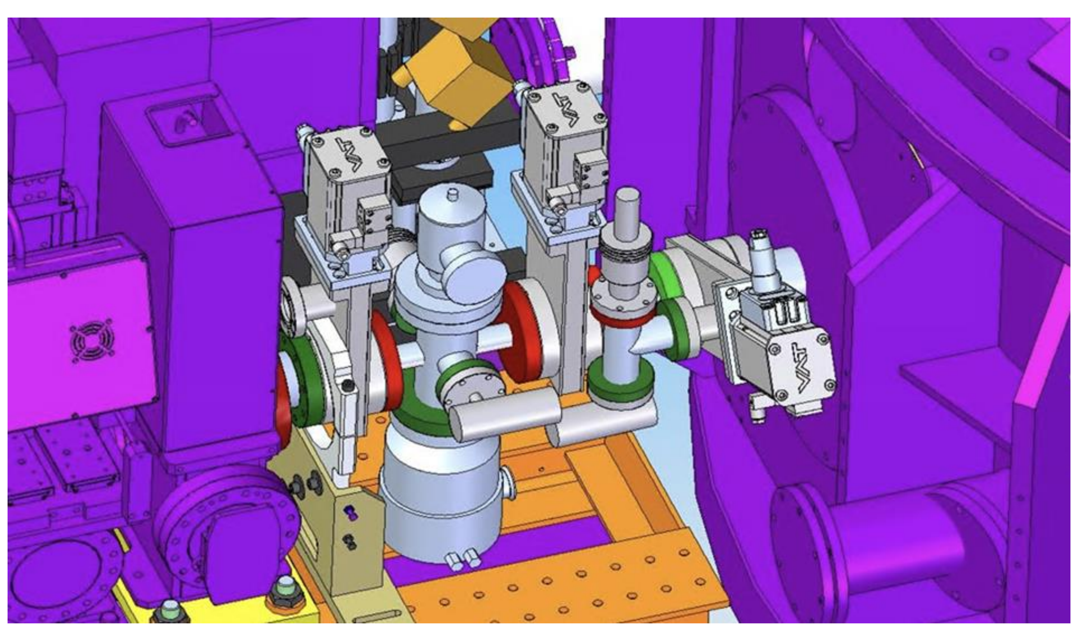
Introduction

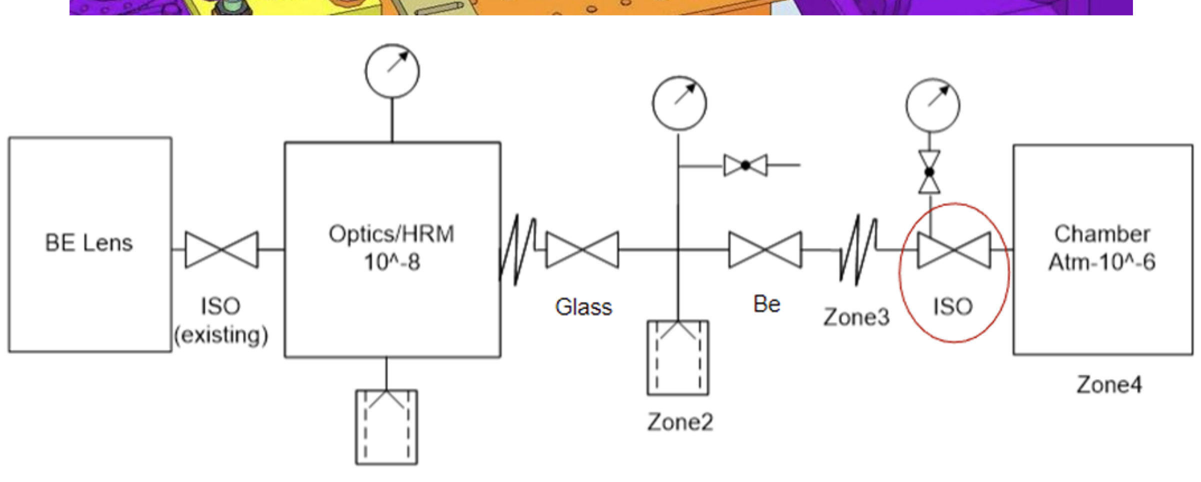
Current configuration of the MEC beamline

Be window for XFEL: Allows for only in-vacuum experiments

Glass window is for alignment laser only: In-air, but does not allow XFEL transportation

- In air experiments are not possible because the 25µm beryllium window is not safe to operate with 1 atm differential pressure across it.
- Investigate how to make in-air experiments possible.





During experiments with the XFEL, only the beryllium window is inserted to achieve high transmission. However, this requires the chamber to maintain a vacuum to avoid window failure.

Replacing the existing fused silica window isolation(ISO) valve:

- a diamond window will allow the ISO valve to be inserted during experiments.
- Closing the ISO valve allows the diamond window to maintain vacuum in the XRT, and transport the XFEL to TCC, while the target chamber is at atmosphere.

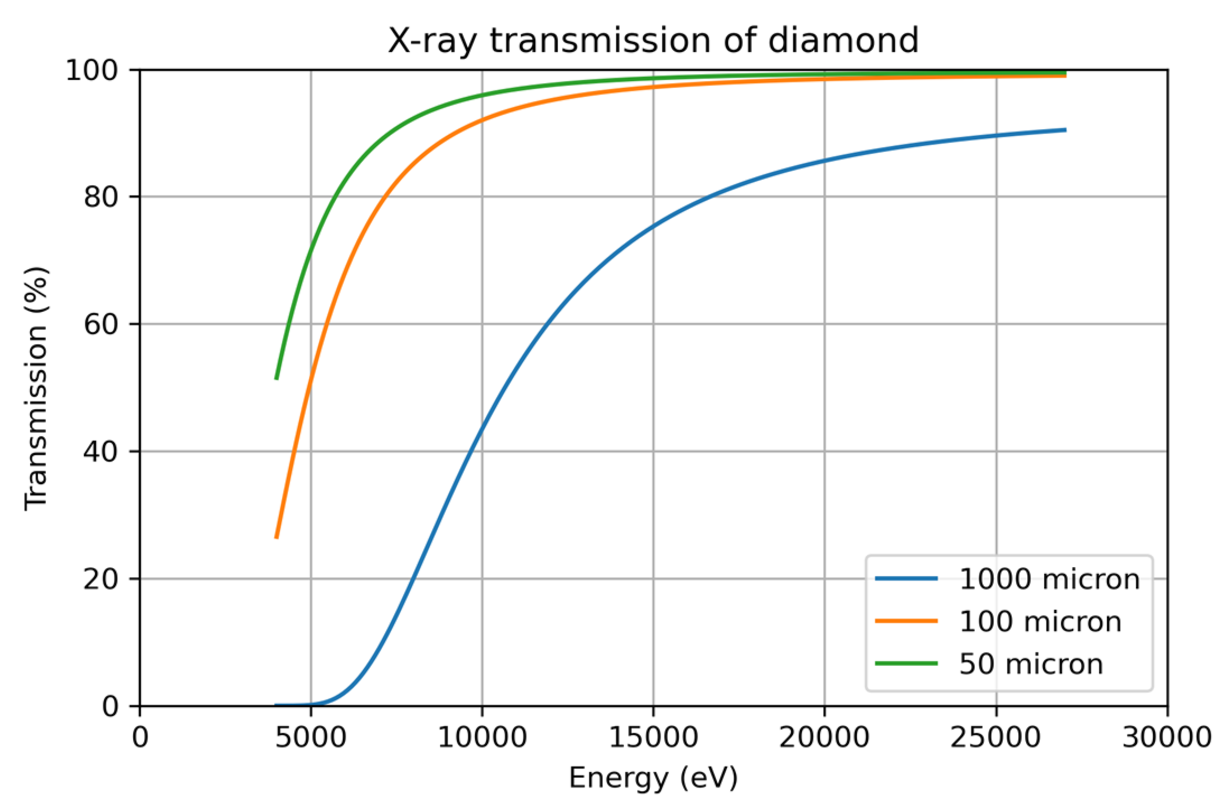
Engineering Approach

Find a solution that minimizes time, cost, and engineering effort to add in air experiment capabilities to the MEC instrument

- Investigate viability of standard diamond window
  - Quote for 1 unit (Diamond Materials GMBH): $840
  - 20 mm diameter : 100 µm thickness
  - 100 um thickness commonly used at synchrotron
  - Pressure tested at 0.620528 MPa safety factor of 6

Transmission Analysis

- Inserting the diamond window into the XFEL beam attenuates the beam
- Transmission is dependent upon the X-ray photon energy



X-ray transmission through synthetic diamond (100 µm thick)

- Over 80% at 7.2 KeV
- Over 90% at 9 KeV

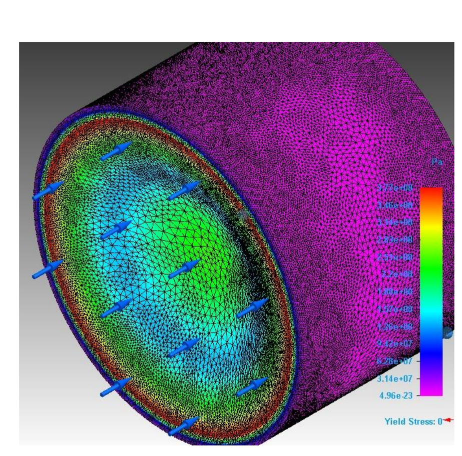
As MEC users move toward higher X-ray photon energy experiments, transmission at higher than 7.2 KeV becomes acceptable.

Finite Element Analysis Simulation

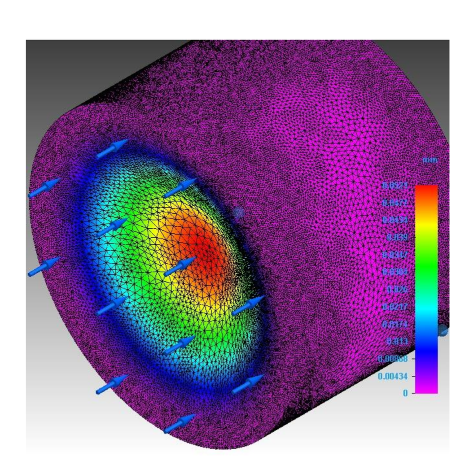
Material properties: 1*

- Young's modulus : 1050 GPa
- Poisson's ratio : 0.1
- Density :3.515 g/cm³
- Tensile Stress: 750 MPa

Simulation results



Stress



Deflection

Due to the limitations of FEA tools available, the shape of the model and boundary conditions are set to allow the window to float across the xy plane and be fixed along the z-axis

- Max Deflection ≈ 52 µm
- Max stress (edge) ≈ 380 MPa
- Stress center = 250 MPa

Analytical Solution

Simplified Equation: 2*

$$t_W = [0.5A_W]\left[\frac{K_W f_s \Delta P}{S_F}\right]^{1/2}$$

- ΔP - Pressure Differential: 0.1103 MPa
- S_F - Fracture Strength: 750 MPa
- K_W - Clamped constant: 0.75
- F_s - Safety factor: 4
- Aw – Window Diameter: 15mm

Solve For:

- Tw – Window Thickness: 157um

This equation is simplified with unknown boundary conditions. The estimate seems conservative.

Large deflection circular plates equation: 3*

$$\frac{qa^4}{Et^4} = K_1\frac{y}{t} + K_2\left(\frac{y}{t}\right)^3 \quad K_1 = \frac{5.33}{1-\nu^2} \quad K_2 = 0.857$$

$$\frac{\sigma a^2}{Et^2} = K_3\frac{y}{t} + K_4\left(\frac{y}{t}\right)^2$$

(At center) $K_3 = \frac{2}{1-\nu}$ $K_4 = 0.50$

(At edge) $K_3 = \frac{4}{1-\nu^2}$ $K_4 = 0.0$

v = Poisson's ratio: 0.1

E = Young's modulus: 1050 GPA

a = Outer radius: 7.5 mm

t = Thickness: 0.1 mm

q = Pressure difference: 0.1103 MPa

For a diameter of 15 mm

Equation 1 Solves For

Y - Max deflection = 59 µm (large deflection)

Equation 2 Solves For

σ e - Max Stress Edge = 441 MPa

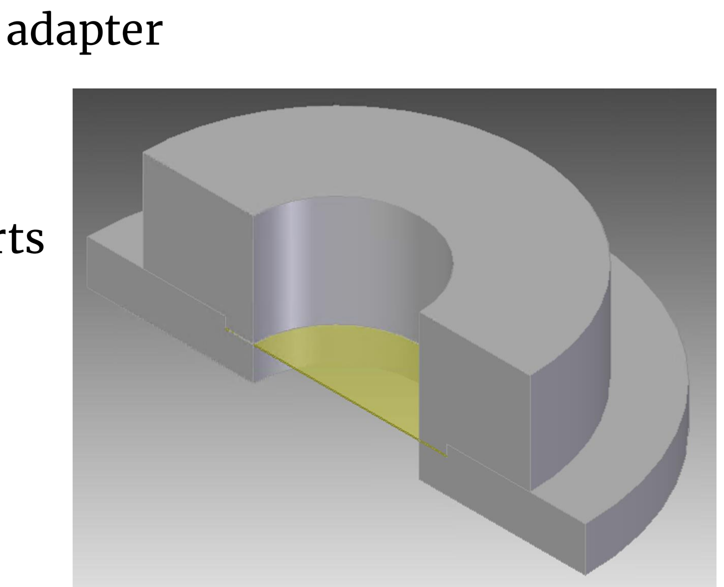
Safety factor of 1.7

σ c - Max Stress Center = 275 MPa

Safety factor of 2.7

Next steps and future work

1. Engineering Design
   Fit diamond window to existing VAT valve in MEC using custom window adapter
2. Procure
   a. Diamond window
   b. Window adapter parts
   c. Gate Valve
3. Installation
4. Controls Integration



ACKNOWLEDGEMENTS

I'd like to thank my mentor Brice Arnold and Hae Ja Lee for their support on the Diamond Window project

*REFERENCES

1. Diamond handbook- Diamond Materials GMBH
2. Opto-Mechanical Systems Design, Volume 1 – Paul Yoder and Daniel Vukobratovich
3. Roark's Formulas for Stress and Strain- WARREN C. YOUNG