Multiphysics Analysis of a High Power RF Window using COMSOL®

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INTRODUCTION

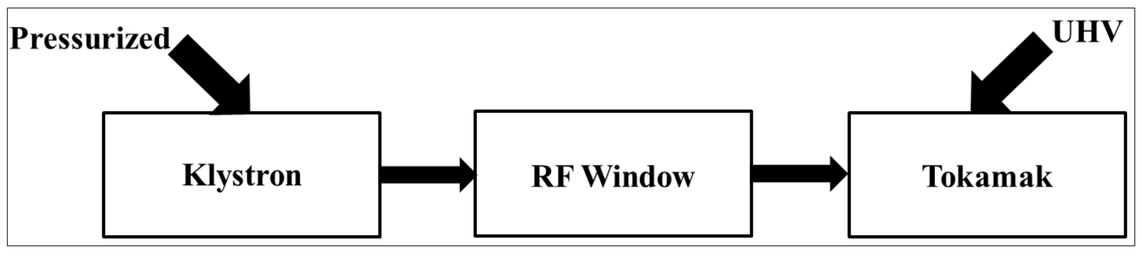

Figure 1. Basic Block Diagram of the complete system

- Nuclear fusion experiments performed in machines 'tokamak'
- Tokamak is under Ultra High Vacuum (UHV).
- Transmission lines feeding power are under ~4 bar pressure.
- RF vacuum window required to mechanically isolate the systems and allow RF power to transmit with high return loss.

COMPUTATIONAL METHODS AND RESULTS

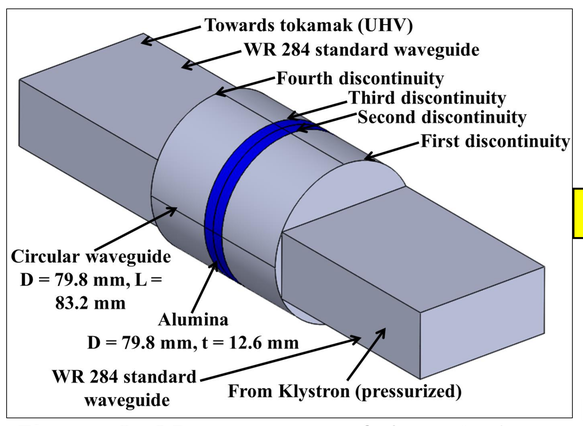

Figure 2. 3D structure of the window

RF Module, Electromagnetic waves, frequency domain (emw) interface used. f = 3.7 GHz, P = 125 kW

Impedance Boundary condition used on the inner surface to resolve the skin depth of copper.

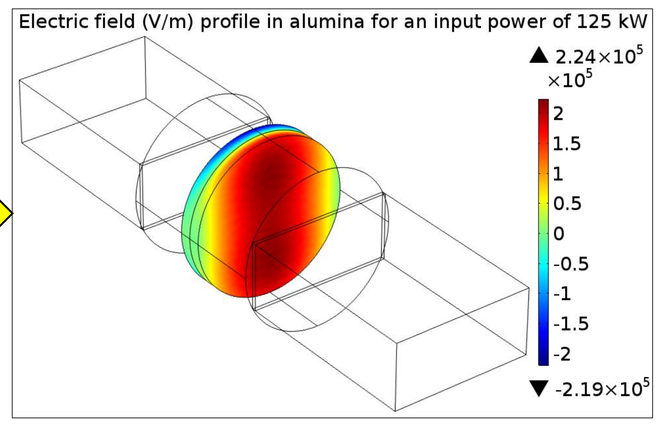

Figure 3. E-field in alumina

- Return Loss ~40 dB
- Power absorbed by alumina ~450 W
- Surface Loss ~ 180 W
- Losses act as heat load for thermal analysis

Heat Transfer Module, Heat Transfer in Solids (ht) interface used.

Heat flux boundary condition used on the outer surface of copper to model convection cooling.

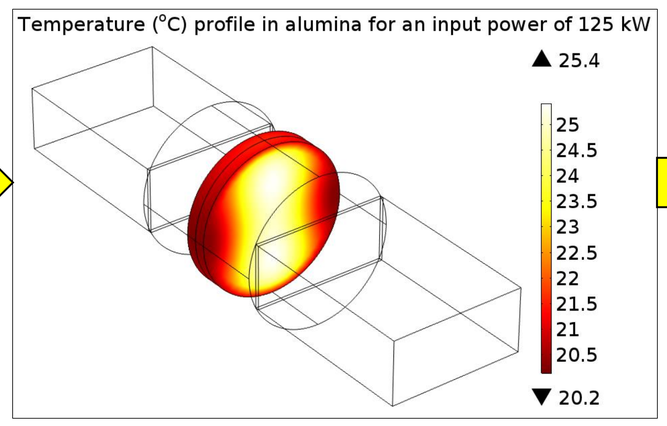

Figure 4. Temperature profile in alumina

Peak Temperature = 25.4 degC

Structural Mechanics module, solid mechanics (solid) interface used.

Fixed constraint boundary condition used at inputs and around the ceramic periphery. Boundary load condition used for PD.

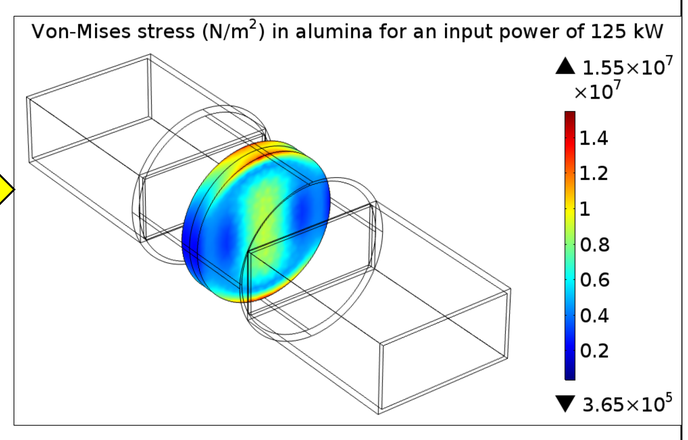

Figure 5. Stress profile in alumina

Max. Deformation = 1.8 μm

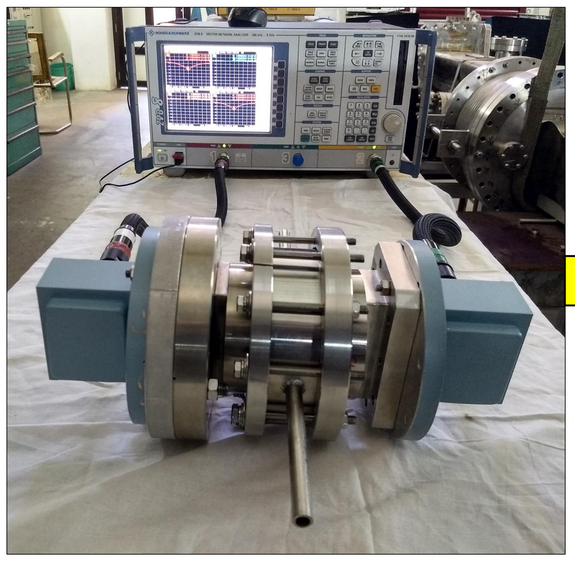

Figure 6. LPT of the fabricated window

RF window was fabricated using alumina and copper

S-parameter characterisation was done using Vector Network Analyser (VNA)

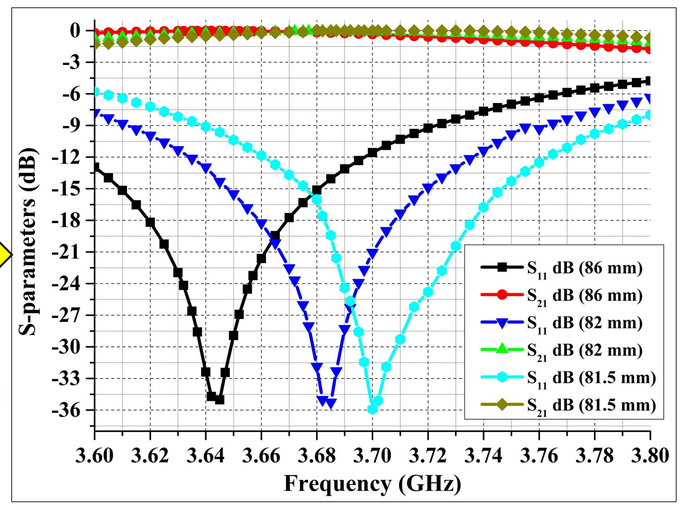

Figure 7. Measured Frequency response of the fabricated window

- Good agreement between the simulated COMSOL® results and the measured results
- Measured return loss ~36 dB (simulated ~40 dB)

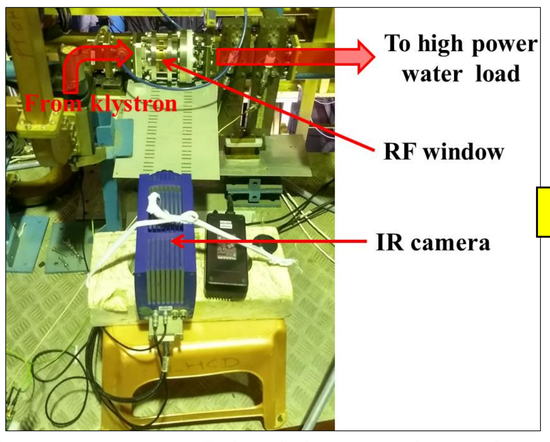

Figure 8. HPT of the fabricated window

High power testing at 125 kW for 1 s , 3.7 GHz was done using klystrons

IR camera was used to measure the temperature at the periphery of the alumina

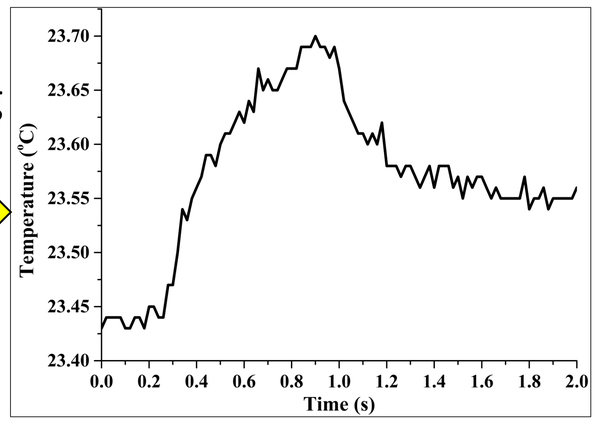

Figure 9. Temperature profile observed by the IR camera

- Peak temperature detected by the IR camera ~23.7 degC at the periphery which matches with the temperature obtained by COMSOL® simulations.

CONCLUSIONS: RF Vacuum window was designed and analyzed using COMSOL Multiphysics®.
The fabricated window was tested and the measured results were found to be in good agreement with the simulation results
Such windows are used in Nuclear fusion experiments and a window for higher power CW operations can be designed.

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