Thermal and Electromagnetic Analysis of materials for RF window of C-band 250 kW CW high power klystron

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Abstract: *The paper presents the thermal analysis of RF window for C-band 250 kW CW power klystron using different materials such as Alumina, Aluminium Nitride and Diamond . The thermal analysis of the window has been carried out using the ANSYS software. The proposed window is designed for 5 GHz operating frequency for handling 250 kW of RF power. In the proposed window geometry, metallized disc of diameter 56 mm and thickness 1.5 mm is brazed in a cylindrical waveguide of diameter 56 mm. The cylindrical waveguide is terminated to WR 187 waveguide at its both ends. Different temperature profiles are obtained for above three materials. Cooling channel designed around the window outside surface for proper cooling of the window by flowing coolant in it. The coolant flow rate changed from 5 to 15 L/min to check the cooling effect with variation of flow rate and found that 5 L/min. flow rate is effective for the structure for cooling the required power dissipation. The window performance has been found satisfactory for microwave transmission.*

Keywords: RF Window; Klystron; pill-box type; alumina; AIN; Diamond.

INTRODUCTION

RF window is one of the important issue for developing the high power klystrons. RF window is a critical component of all microwave high power tubes and is used on the output section of the device for the transport of microwave power from vacuum to external pressurized atmosphere. RF window is a passive component that must be transparent to microwaves and hold ultra high vacuum. The desired features of an ideal window are: minimum reflection, minimum insertion loss, high power handling capability, wide bandwidth, excellent mechanical strength, high thermal shock resistance and vacuum tightness. Pill-box type microwave windows are generally preferred for high power klystrons due to their higher capacity for handling high peak and average rf power. The other functional advantages are broad bandwidth and easy impedance matching with the rest of the transmission line.The design studies on high power RF windows are motivated by the need for C band 250 kW CW power klystron which is under development at CEERI Pilani.

Specifications of C-band klystron

Operating Frequency	5 GHz
Output Power	250 kW CW
Beam Voltage	60 KV
Beam Current	10 Amps
Focusing	Electromagnet
Efficiency	> 40 %
Gain	> 45 dB

WINDOW SIMULATION

The electrical design parameters for the window are: thickness, diameter and dielectric constant of alumina disc, diameter and length of waveguide etc. The electromagnetic structure of window simulated using CST microwave studio code The thermal simulation and analysis for the same structure have been carried out with ANSYS software. Since electromagnetic and thermal properties of window materials play imported role in the design of RF window. Comparative study of temperature profile for three materials carried out keeping the same geometrical structure of window as given below.

Input Design Parameters:

Window Material	= Alumina, AIN, Diamond
Disc diameter	= 56 mm
Disc thickness	=1.5 mm
Circular W/G diameter	=56 mm
Circular W/G length	=25.01mm
Rectangular W/G length	=30 mm
Input and output W/G (WR187)	a= 47.55 mm
	b=22.15 mm

Thermal Analysis using ANSYS: Since this window is to be used for 250kW CW power klystron so, thermal analysis of this window is also necessary. This thermal analysis has been done using ANSYS code. The main approach of this software is the Finite Element Method. A steady state thermal analysis calculates the effects of steady thermal loads on a system or component. You can use steady state thermal analysis to determine temperatures, thermal gradients, heat flow rates and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following

- Convection
- Radiation
- Heat flow rates
- Heat fluxes (heat flow per unit area)
- Heat generation rates (heat flow per unit volume)
- Constant temperature boundaries

The desired features of microwave window vary with the types of their application. Nevertheless, a window ought to be almost loss less and reflection less. It must withstand high power, thermal and mechanical stresses and pressure gradient. Therefore care must be taken in selecting the power window material with low loss tangent, high thermal conductivity and mechanical strength. The thermal simulation of different parameters for window such as window dielectric materials, variable loss tangent, coolant flow rate, transmitted power v/s temperature rise for symmetric window geometry are presented.

Input parameters used in simulation are:
Material property, Coolant property, Heat flux, Film coefficient and Bulk temperature.

The values of input parameters for Ansys code involved in thermal design of window are:
Bulk temperature =25 C
Water flow rate = 5 L/min.
Film Coefficient =8184 W/m²K
Input power =250 kW
The various temperature profiles obtained using Alumina, AIN and Diamond are shown below in figure1, figure2 and figure3 respectively.

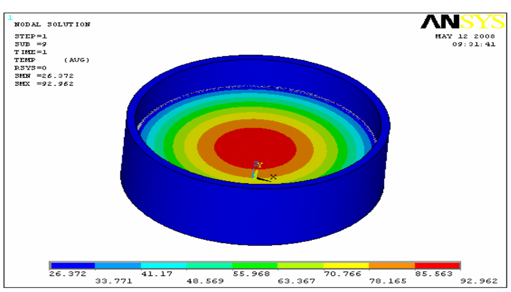

Figure 1. Temperature profile of window using Alumina at 0.005dB insertion loss.

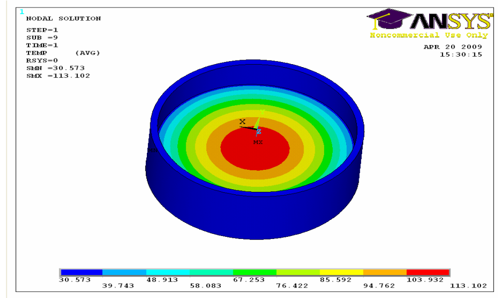

Figure 2. Temperature profile of window using AIN at 0.005dB insertion loss.

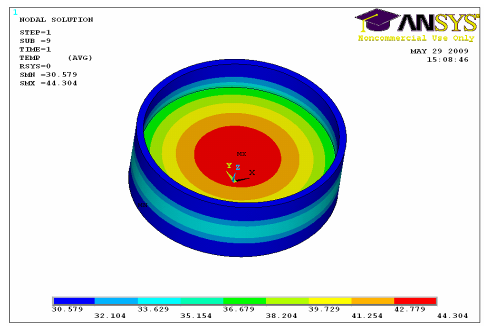

Figure 3. Temperature profile of window using diamond at 0.005dB insertion loss.

The comparison in temperature rise for all the three disc materials is shown in the graph below in figure 4.

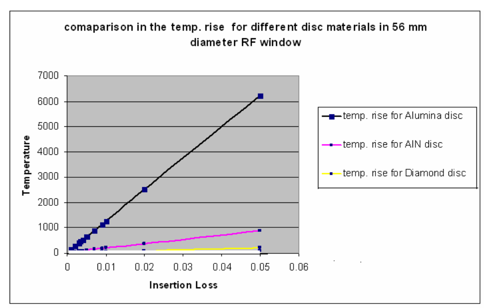

Figure 4. Comparison graph of all materials

The temperature gradients obtained for all these materials at different power loss in the same geometry of window are tabulated in Table1.

Table 1. Temperature results of different materials.

Power loss In disc material (W)	Heat flux (W/m)	Temp. Grad. (Alumina Disc)	Temp. Grad. (AlN Disc)	Temp. Grad. (Diamond Disc)
57.49	23331.98	26.1-149.5	26.1- 42.6	26.1-28.9
120.69	48982.02	27.3-286.5	27.3- 62.0	27.3-33.1
172.63	70064.16	28.3-399.1	28.3-77.9	28.4-36.6
230.03	93356.33	29.4-523.5	29.4-95.5	29.5-40.5
287.17	116546.27	30.5-647.3	30.5-113.1	30.6-44.3

WINDOW BRAZING

In order to maintain ultra high vacuum the window should be capable of holding vacuum of the order of 10^{-9} torr. The alumina disc is metallized and brazed on the circumference with OFHC copper waveguide, with cylindrical part made extra thin at the joint area, and the disc is pushed to be fitted in it. A molybdenum wire clamp is placed on the outside of the waveguide in this region to keep the copper from expanding away from the ceramic during brazing. Palladium brazing alloy with MP 850 ^{0}C has been used to make the vacuum tight joint. The copper part has been made thin to make it ductile so that the seal may remain intact instead of mismatching of thermal expansion of both materials. The brazed window is leak checked on helium leak detector of sensitivity of $1x10^{-10}$ torr lit/sec[1]. The brazed window is shown below in Figure 5.

Figure 5.RF window parts

CONCLUSION

Thermal analysis of pillbox-type RF window for high power C-band klystron has been carried out using ANSYS. The three types window dielectric materials i.e. alumina, AlN and diamond have been analyzed and temperature profile obtained with proper cooling arrangements. The simulated results for alumina material are validated through cold test measurements on experimental windows. The thermal analysis predicts that up to 100 kW alumina material window could be realized and for higher rating AlN more promising material for RF window of high power klystron..

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