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Output window for high power Gyrotron

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***Abstract*—*In this paper, the design and development of output window for high frequency and high power Gyrotron have been carried out. The design and development of edge cooled single disc RF window for 170 GHz Gyrotron has been carried out. A diameter and thickness of the ceramic window are 90 mm and 3.2 mm, respectively, whose edge is directly cooled by water. The return loss (S_{11}) and insertion loss (S_{21}) of the window have been obtained as -47.5 dB and -0.02 dB respectively. In this paper thermal analysis of RF window has also been carried out using ANSYS software. The disc center and disc edge temperature has been found as 385 K and 288 K, respectively. The cold characterizations have also been carried out using Vector Network Analyzer (VNA). It is also found that simulated results are close to the experimental results.*

***Keywords*— Gyrotron, Alumina ceramic, Gaussian mode, RF window, S-parameters.**

I. INTRODUCTION

Gyrotron oscillators are high power microwave sources mainly used for electron cyclotron resonance heating (ECRH) and plasma stabilization through the localized current drive in the magnetically confined plasmas for the controlled thermonuclear fusion experiments [1]. Gyrotrons have wide applications in the field of plasma diagnostics, material processing, radar systems, communications, medical research, etc. Interest in Gyrotron has grown tremendously due to its potential application in energy generation from fusion energy under global International Thermonuclear Experimental Reactor (ITER) program. The Gyrotron output system consists of an output taper which connects the cavity with the quasi-optical mode converter and the RF window. Fig.1 shows the schematic view of Gyrotron output system [2]. Gyrotron window is required for transmitting significant amount of microwave energy without exhibiting thermal runway. The design requirement of the window is that it should withstand high power handling, mechanical and thermal stresses, vacuum leak tight joining, etc. Therefore care must be taken in selecting a proper window material with low loss tangent, high thermal conductivity, suitable mechanical strength and perfect design to minimize power reflection and absorption for better transmission. The desired features of an ideal window are minimum return loss, minimum insertion loss, high power handling capability and wide bandwidth. The material selection is very important for a Gyrotron window operating at high power and high frequencies [3]. For high power Gyrotrons the advanced materials such as alumina, sapphire, chemical vapor deposited (CVD) diamond, born nitride (BN), etc. have to be used. Gyrotrons operating at 24-70 GHz with moderate power capabilities, generally use double discs RF window which allow surface cooling to keep the disc temperature below a safe limit. But it is always preferable to use single disc edge cooled window because of its simplicity of fabrication and reliability.

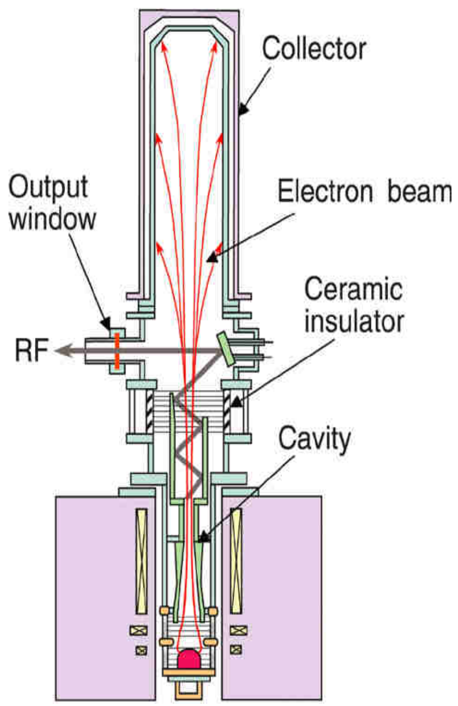

Fig. 1: Schematic view of high power Gyrotron

II. DESIGN OF RF WINDOW

The electrical design of edge cooled single disc alumina window for 170 GHz, 1MW Gyrotron has been carried out using CST microwave studio. A diameter and thickness of the ceramic window are 90 mm and 3.2 mm, respectively, whose edge is directly cooled by water. The

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return loss (S_{11}) and insertion loss (S_{21}) of the 170 GHz Gyrotron window have been obtained as - 47.5 dB and - 0.02 dB respectively. The window disk thickness and diameter are optimized considering minimum return loss and minimum insertion loss using by CST microwave studio. On the basis of electrical design parameters, the window thickness is estimated as 3.2 mm and diameter 90 mm selected for electrical design. The important aspects of high power window development are the dielectric characteristics of the window materials, that is, the loss factor (*tan δ*) and the relative permittivity ($\boldsymbol{\varepsilon_r'}$) because they directly affect power absorption and reflection. The thickness (*d*) of a window disc is designed so that the power reflection is minimized[4]. To avoid the reflections of an incident wave from the window disk, the thickness *d* should be equal to an integer multiple of half-wavelength corresponding to the operating frequency (f), so that, ($d = n\lambda/2\varepsilon_r^{1/2}$) where *n* is an integer, *λ* is the free space wavelength and ε_r is the permittivity of window material. Fig. 2 shows the schematic diagram of edge cooled window for high power gyrotron. Fig. 3 shows the model of single disc RF window used in simulation. The CVD diamond and alumina windows can be used for 1MW Gyrotron due to suitable thermal conductivity and low dielectric loss. It is found that Sapphire and BN can be used in moderate power Gyrotron but Alumina and CVD diamond is must for megawatt Gyrotron. Table 1 shows the materials properties used for electrical and thermal design of RF window. Fig.4 shows the return loss (S_{11}) and insertion loss (S_{21}) performance of the single disc alumina RF window for 170 GHz Gyrotron using CST microwave studio [6].

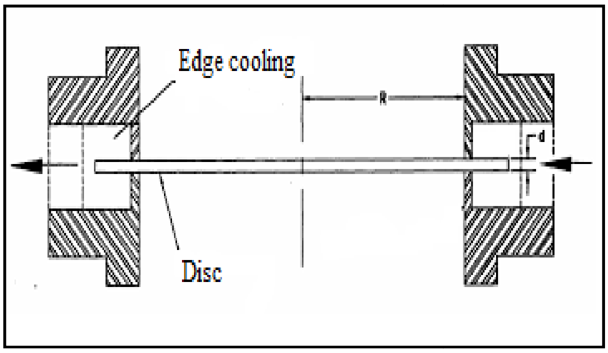

Fig. 2: Schematic view of Gyrotron output window

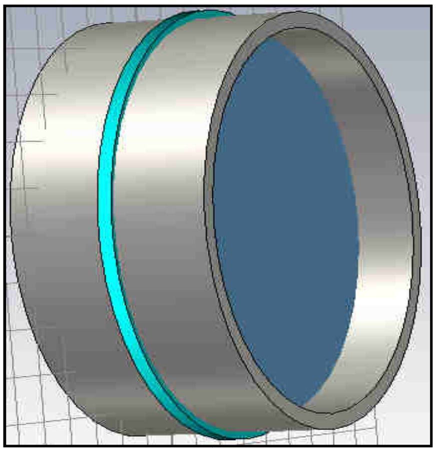

Fig.3: CST model of single disc window for 170 GHz

A transient thermal analysis of window has been carried out to determine temperature distribution as a function of time using ANSYS software [7]. The aim of the thermal analysis is to assess temperature distribution on RF window for 170 GHz Gyrotron during extreme case of operation. The analysis of edge cooled disk can be approximated by a disk which is insulated on its two faces and cooled on its edge only at the same location the mounting boundary conditions are applied. The maximum temperature of the Gyrotron window depends on the RF power absorbed in the alumina disc. The beam-wave interaction simulation shows 1MW RF power generations in interaction cavity and thus 2420 W RF power (0.22%) is absorbed by the window disc. This absorbed power is then distributed in Gaussian form all over the disc surface as the quasi optical mode launcher converts the RF power from very high order mode to the simple and low loss Gaussian mode.

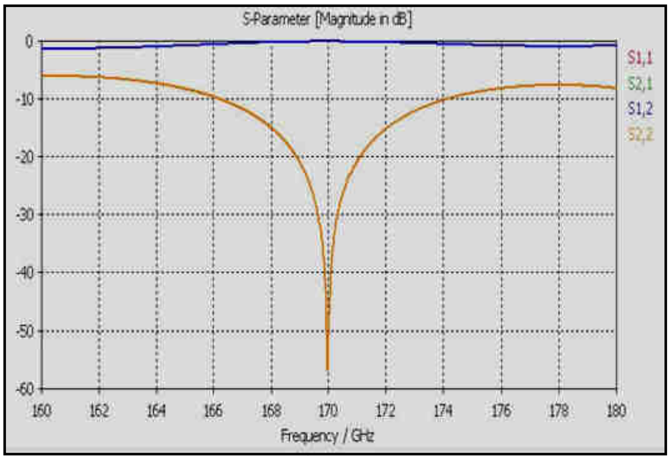

Fig.4: Return loss performance of 170 GHz RF window using CST

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Table 1 -Properties of different dielectric materials

Parameters	Alumina	CVD diamond
Thermal Conductivity k (W/m.K)	34	2000
Permittivity ($\varepsilon_{r'}$)	9.8	5.67
Density ρ (kg/m^3)	3900	3520
Bending Strength σ_B[MPa]	380	500
Poissons Number (ν)	0.25	0.1
Specific heat c_p(J/kg.K)	780	520
Loss tangent ($\tan\delta*10^{-5}$)	20	2
Young's modulus E	300	1050
Coefficient of thermal expansion α [10^{-6}/K]	6.3	1.0

The heat flux is given as an input parameter in the thermal simulations, which is 44.22 W/cm^2 in the present case. The input parameters are material property, coolant property, heat flux, film coefficient and bulk temperature. The cooling channel has been designed around the window outside surface for proper cooling of the window. The RF window optimized design allows low heat loads in the ceramic and consequently low temperature increase and low stresses. The window geometries are analyzed for the effective cooling. Normal water (288 K) is used as a coolant in thermal simulations of the RF window. The heat film coefficient is optimized considering the effective cooling of the window disc. Fig.5 shows the mesh geometry of RF window using ANSYS. Fig. 6 shows the contour plot of the temperature distribution in window disc at $h=10^4$ W/m^2.K for Gaussian distributed. The disc center and disc edge temperature are found as 385 K and 288 K, respectively.

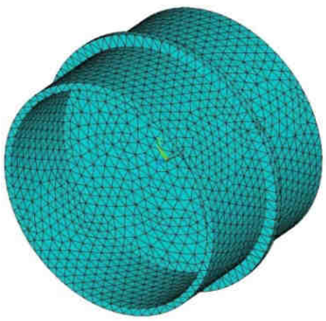

Fig.5. Mesh geometry of RF window using ANSYS

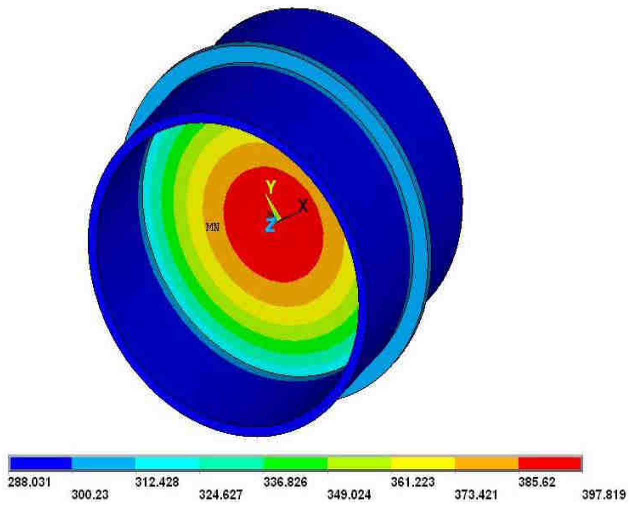

Fig.6: Temperature distribution on disc with heat flux 44.22 W/cm^2

III. DEVELOPMENT OF WINDOW

For the sake of experimental validation, a highly purity alumina (99.9%) RF window based upon design has been developed and cold characterization has also been carried out using Vector Network Analyzer [8]. An Alumina disc is situated exactly at the centre of the window. The alumina ceramic to metal joining is critical in fabrication of RF window. Metalized alumina disc of 90 mm diameter and 3.2 mm thickness was brazed in the copper circular waveguide using Ag/Cu brazing alloy. A molybdenum wire arrester winding around the copper waveguide for minimizes the thermal stresses. These stresses develop during cooling cycle have been taken care by thinning joint of copper waveguide. Fig.7 shows the developed single disc alumina RF window for 170 GHz Gyrotron. Fig.8 shows the cold test measurement setup for S-parameters using horn antenna free space method. Here for this method, WR-5 standard horn antennas have been used. Fig.9 shows measured return loss performance of 170 GHz single disc window using free space horn antenna method. It is of interest to mention that the measured value is matching with the simulated value of return loss obtained.

Fig.7: Developed single disc alumina RF window

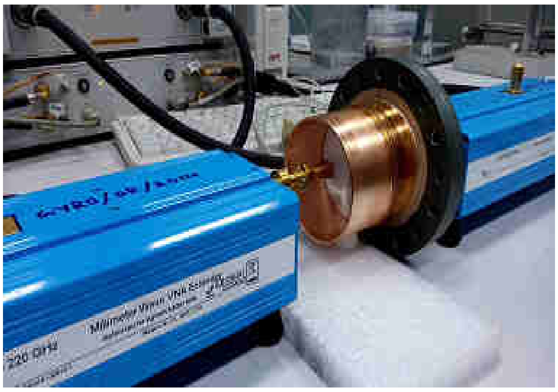

Fig.8: Cold test setup of RF window using free space method

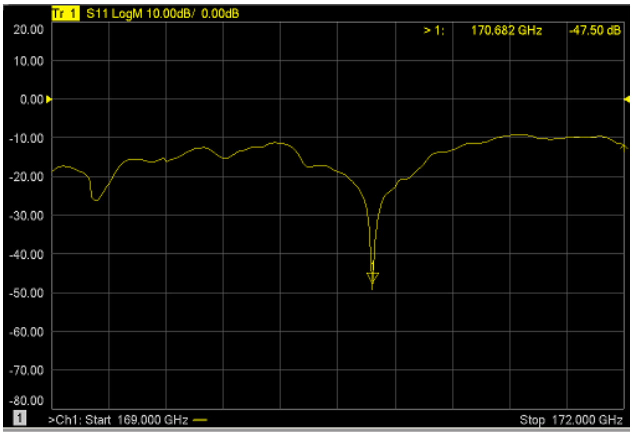

Fig.9: Measured return loss (S_{11}) performance of RF window

IV. CONCLUSION

The design and development single disc edge cooled RF window have been carried out. The thermal study of RF window for 170 GHz Gyrotron has also been carried out using ANSYS. In the presented design, the temperature on the alumina ceramic disc of RF window did not exceed 100^{o} C and found in safe limit. A technique for joining metal to ceramic has been developed. In conclusion, it has been established that available RF window designs are capable of handling the thermal and mechanical loading of megawatt Gyrotron. It is also found that simulated results are close to the measured results.

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