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Design and Simulations of Low Loss Single Disk RF Window

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ABSTRACT

This paper describe three simple designs of pillbox type S-band RF window for 2.5 MW peak power operation. In these designs alumina ceramic disk is used as RF transmitting medium, which is brazed with pill-box copper to create vacuum seal. Three different fabrication configurations of RF window are simulated using CST Microwave Studio. The simulation results for one of the designs are quite promising. At the working frequency of 2.998 GHz, the return loss S11 and transmission loss S21 are -72.75 dB and S21 is -0.009 respectively. The power loss at window is just 5.2 W, indicating that forced cooling of window is not required. PACS: 87.50.Jk; 84.40.Ba

1. Introduction

RF window is a vital component of all RF based particle accelerators and high power microwave sources like magnetrons, klystrons, gyrotrons, etc. It is employed at output section of the microwave device for transmission of RF power from ultrahigh vacuum to pressurized gas environment in waveguides and then again to ultrahigh vacuum environment in accelerating structures. The window material must be very good in mechanical strength to hold high pressure gradient. In addition, it should be able to transmit maximum RF power with minimum loss at window. From RF transmission perspective, the desired features of an ideal RF window are minimum return and transmission losses, wide bandwidth and high power handling capability. The RF window is a weakest link in the high power microwave sources and particles accelerators because the most frequent failure of these devices occur due to the breakdown of RF windows. Usually breakdown of RF windows are cause by excess heating due to localized RF power dissipation, surface breakdown caused by high electric field and resonant multiplication of secondary electrons [1-3].

Over the years, a variety of innovations and improvements to RF windows have been reported for high power microwave sources and particles accelerators [1, 4–7]. The efforts are still on to further improve operation and mechanical parameters of the RF window. The pillbox type RF windows remain of particular interest due to their advantages including easy way to match impedance and broad frequency response just by adjusting the dimensions of the window. In this work we present three simple designs of S-band alumina ceramic based pill-box RF window. The mechanical dimensions are optimized by S-parameter analysis using CST Microwave studio. The return and transmission loss of the best design are compared with the values available in literature.

5. Theory

The characteristic parameters like impedances Z_{cir} and Z_{rec} for circular and rectangular waveguides respectively are defined as while taking relative permeability equals to unity for non magnetic materials :

$$Z_{cir} = \frac{377}{\sqrt{\varepsilon_r}} \frac{\lambda_{gc}}{\lambda_o}, \quad (1)$$

$$Z_{rec} = \frac{377}{\sqrt{\varepsilon_r}} \frac{b_r}{a_r} \frac{\lambda_{gr}}{\lambda_o}. \quad (2)$$

Where, ε_r is relative permittivity of the dielectric medium. While, λ_{gc} and λ_{gr} are guide wavelengths for circular and rectangular waveguides and a_r, b_r are long and short sides of rectangular waveguide respectively. Relations for λ_{gc} and λ_{gr} are defined as :

$$\lambda_{gr} = \frac{\lambda_o}{\sqrt{1-(\frac{\lambda_o}{2a_r})^2}}, \quad (3)$$

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$$\lambda_{gc} = \frac{\lambda_o}{\sqrt{1-(\frac{\lambda_o}{1.706d})^2}}, \quad (4)$$

Where, λ_0 and λ_g are free space wavelength and cutoff wavelength in the waveguide and d is diameter of circular waveguide. Now the transmission is maximum when the impedances of rectangular and circular waveguides matches that is

$$\frac{Z_{cir}}{Z_{rec}} = \frac{a_r}{b_r}\frac{\lambda_{gc}}{\lambda_{gr}}, \quad (5)$$

is unity. Since the circular waveguide is partially filled by dielectric medium and we can treat this waveguide as filled with a dielectric having an effective relative permittivity [8]. Then the equation (5) modified as

$$\frac{Z_{cir}}{Z_{rec}} = \frac{a_r}{b_r}\frac{\lambda_{gc}}{\lambda_{gr}\sqrt{\varepsilon_r'}}. \quad (6)$$

Generally, in high power pill box type RF window the value of effective permittivity lies between 1 and 2. For impedance matching of the two types waveguides, we can write

$$\frac{\lambda_{gc}}{\lambda_{gr}} = \frac{b_r}{a_r}\sqrt{\varepsilon_r'}. \quad (7)$$

We have simulated RF window by matching impedance of rectangular and dielectric filled circular waveguide.

3. Modeling and Simulations

Our RF window model mainly consists of a pillbox cavity and standard WR-284 input and output ports with a dielectric disk embraced at centre of the cavity. Here, the pillbox cavity along with the waveguide ports are consider to be made of pure copper with electrical conductivity of 5.97×10^7 S/m. While the dielectric disk material is considered as 96% pure alumina with relative permittivity and relative permeability 9.4 and 1.0, respectively.

Considering the brazing and fabrication limitations of our mechanical workshop, three different designs were investigated using CST Microwave Studio simulations. In first two designs, alumina disk is brazed with bulk copper using kovar as intermediate brazing material, where kovar is a nickel–cobalt ferrous alloy. The mechanical and electrical properties of kovar used in simulation are given in Table 1.

In order to avoid mechanical deformation and cracking due to different thermal expansion coefficient of copper and alumina, a U-shaped kovar ring of two configurations is suggested for brazing joint between alumina disk and bulk copper. The schematic of these arrangements with dimensions optimized by simulation are shown in Fig. 1(a) and Fig. 2(a). In first case, a space is allowed on both sides of the brazing joints. While, in second case space is on one side of the brazing joint. The third fabrication arrangement under consideration is to braze a 1 mm thick and 5 mm wide copper ring at periphery of the alumina disk and then join copper ring with the bulk copper by electron beam welding as it is proposed in reference [11]. The schematic

Table 1: Thermal and electrical properties of kovar

Property	Value	Unit
Density [9]	8000	kg/m^3
Thermal conductivity [9]	17	W/(m-K)
Electrical conductivity [9]	2.04×10^6	S/m
Thermal expansion coefficient [9]	5.5×10^{-6}	/k
Relative permeability (μ_r) [10]	1000	nil

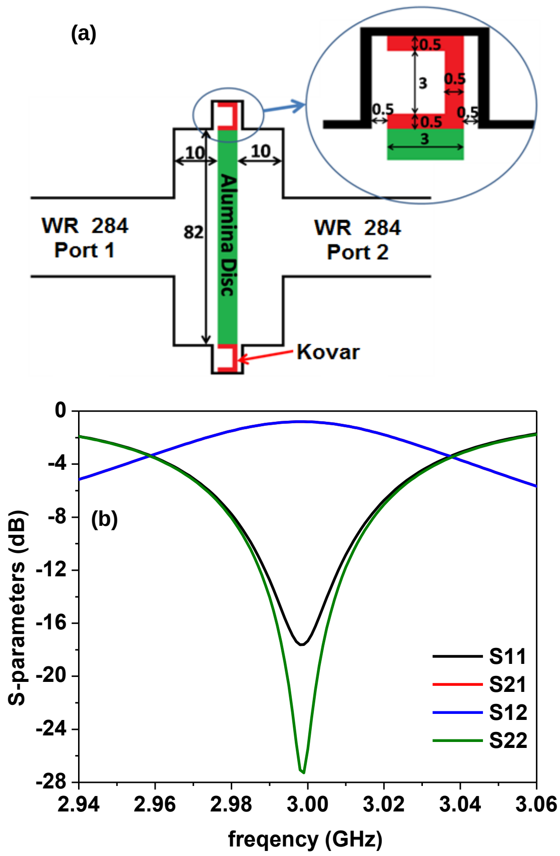

Fig. 1. (a) 2-D schematic diagram of pillbox type RF window with single alumina disc brazed through a u-shaped kovar with copper having space on both side of brazing joint. The dimensions shown are the optimized one for minimum return and transmission losses. In the inset kovar ring dimensions are shown. (b) Simulated values of the transmission loss (S21, S12) and return loss (S11, S22) for the above mentioned arrangement

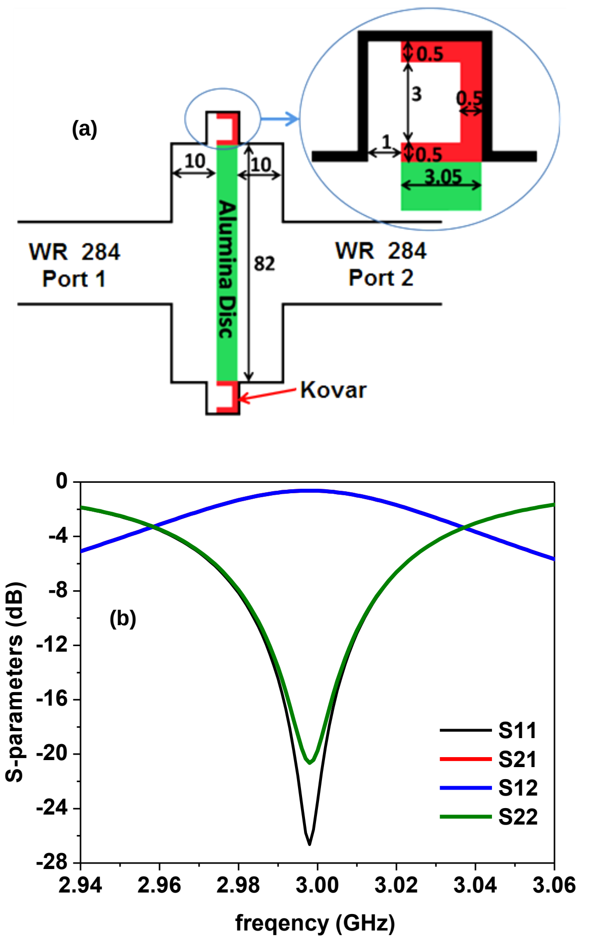

Fig. 2. (a) 2-D schematic diagram of pillbox type RF window with single alumina disc brazed through a u-shaped kovar with copper having space on one side of brazing joint. The dimensions shown are the optimized one for minimum return and transmission losses. In the inset kovar ring dimensions are shown. (b) Simulated values of the transmission loss (S21, S12) and return loss (S11, S22) for the above mentioned arrangement

with optimized dimensions of this configuration is shown in Fig. 3(a). These RF windows were simulated to study the parametric dependencies of return loss (S11 and S22) and transmission loss (S21 and S12). The design was optimized for 2.998 GHz frequency, using tetrahedral mesh with average mesh quality of 0.881.

4. Results and Discussion

We have optimize the design for RF windows by varying the diameter and length of the pillbox cavity along with diameter and thickness of the alumina disk. While keeping the brazing material (kovar) ring dimensions constant. In Fig. 1 (b) the return as well as transmission losses in terms of (S11, S22) and (S21, S12) are plotted for window with free space on both side of u-shaped brazing joint. Here, S11 and S22 at 2.998 GHz are -17.62 dB and -27.06 dB respectively. So in this configuration port 2 will be towards the source as well as high pressure side. Also the transmission losses both S21 and S12 are similar at 2.998 GHz the working frequency. Transmission loss with -0.798 dB at working frequency, 2.5 MW of peak power and 0.001 duty cycle corresponds to power loss of 419.6 W at the window. This power loss will lead to heat generation, which has to be removed from the system.

In Fig. 2b return loss (S11 and S22) and transmission loss (S21 and S12) for the window configuration with free space on one side of u-shaped kovar ring brazing joint is shown. The minimum value of S11 at 2.998 GHz is -26.65 dB while S22 at this frequency is -20.64 dB. So in this configuration port 1 will be toward the source side. Here the transmission loss i.e S21 and S12 both are -0.631 dB at 2.998 GHz frequency. This means that power loss at window for 2.5 MW peak input power and 0.001 duty cycle will be 338.1 W. The heat produced by this power loss has to be removed to avoid failure of the window.

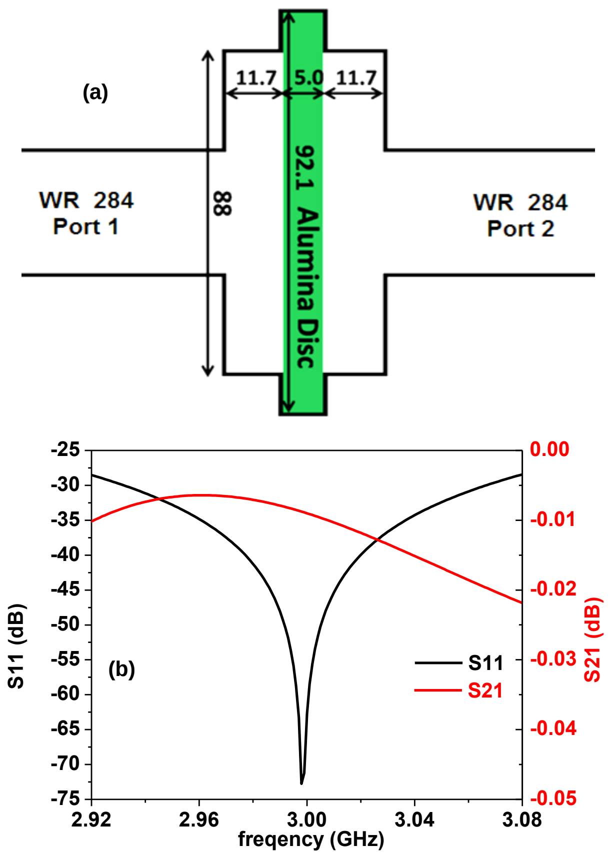

Fig. 3. (a) 2-D schematic diagram of pillbox type RF window with single alumina disc brazed with a copper ring and then this brazed disk is electron beam (EB) welded with bulk copper cavity. The dimensions shown are the optimized one for minimum return and transmission losses. (b) Simulated values of the transmission loss (S21) and return loss (S11) for the above mentioned arrangement

In Fig. 3 (b) the return loss S11 and transmission loss S21 for the third window arrangement are plotted for the frequency ranging from 2.92 GHz to 3.06 GHz. Also S11, S22 and S21, S12 are similar for this arrangement. The return loss and transmission loss for this whole frequency range is less than -28 dB and -0.02 dB respectively. So this window can act as a broadband window with the bandwidth of 140 MHz. At working frequency S11 and S21 are -72.75 dB and -0.009 dB respectively. This corresponds to only 5.2 W power loss at 2.5 MW peak working power and at the duty cycle of 0.001. The heat generated by this power can easily be removed by natural convection. Table 2 shows comparison of return and transmission losses of this design and the values recently reported in literature. It can be seen that return and transmission losses of our design are comparatively low.

Table.2: Comparison of return and transmission losses

Return Loss (S11)	Transmission Loss (S21)
-90 dB [4]	-
-41.3 dB [8]	0.014 dB
-70 dB [11]	-
-32 dB [12]	-0.01 dB
-72.75 dB [This work]	-0.009

In summary, we have investigated three different RF window designs using CST Microwave Studio. These designs can be fabricated using locally available facilities. First two designs with kovar as a brazing joint material between ceramic disk and bulk copper have higher return and transmission losses. These two designs require forced cooling for safe operation of the window. While window design based on electron beam (EB) welded joint with bulk copper pillbox cavity has lowest transmission as well as return losses for a broad frequency band of 140 MHz.

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References

[1] S. Michizono, Y.Saito, H. Mizuno and S. Yu. Kazakov, "High Power Test of Pill-Box and TW in Ceramic Type S-Band Windows", in Proceedings of the 17th International Linac Conference, LINAC94, Tsukuba, Japan, pp. 457-459, August 1994.

[2] S. Michizono, Y. Saito, S. Yamaguchi, S. Anami, N. Matuda and A. Kinbara, "Dielectric materials for use as output window in high-power klystrons", IEEE Trans. Electr Insul., vol. 28, pp. 692-699, 1993.

[3] M. K. Alaria, Y. Choyal and A. K. Sinha, "Design of Single disc RF window for High Power Gyrotron", Journal of Physics: Conference Series, vol. 365, pp. 012057, 2012.

[4] A. D. Yerminian, V. A. Dolgashev and S. G. Tantawi, "High power S-band window optimized to electric and magnetic field on the surface", SLAC-PUB-15459, 2013.

[5] S. Y. Kazakov, Presentation at LC93 Workshop, SLAC, Stanford University, Oct. 1993.

[6] W. R. Fowkes, R. S. Callin, S. G. Tantawi and E. L. Wright, "Reduced Field TE01 X-band Traveling Wave Window", in PAC95, Dallas, pp. 1587-1589, May 1995.

[7] W. R. Fowkes, R. S. Callin, E. N. Jongewaard and S. G. Tantawi, "Large Diameter Reduced Field TE01 Traveling Wave Window for X-band", in PAC99, New York, p. 785, March/April 1999.

[8] O. S. Lamba, Debasish Pal, Dependra Kant, Tanima Girl, M. K. Verma, SC Nangru and L. M. Joshi, "Design and Optimization of Asymmetric RF Window for 6 MW Pulse Power S-band Klystron", IEEE Proc. Int Conf Microwaves, pp. 44-46, 2008.

[9] Wikimedia Foundation Inc. "Kovar", Properties, [Online]. Available: https://en.wikipedia.org/wiki/Kovar. [Accessed Aug. 18, 2016].

[10] CRS Holdinds Inc. "Technical Datasheet", CarTech Kovar Alloy, [Online]. Available: http://cartech.ides.com/datasheet.aspx?E=173. [Accessed Nov. 28, 2016].

[11] F. Gerigk, JM. Giguet, E. Montesinos, B. Riffaud, P. Ugena Tirado and R. Wegner, "The LINAC4 Power Coupler", in Proceedings of IPAC2011, San Sebastian, Spain, pp. 208-210, 2011.

[12] J. Hillairet, J.Achard, Y.S.Bae, J.M.Bernard, N.Dechambre, L.Delpech, A.Ekedahl, N.Faure, M.Goniche, J.Kim, S.Larroque, R.Magne, L.Marfisi, W.Namkung, H.Park, S.Park, S.Poli and K.Vulliez ,"Design and tests of 500 kW RF windows for the ITER LHCD system", Fusion Engineering and Design, vol. 94, pp. 22–30, 2015.