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Design and Development of Pill Box Type RF Window for Millimetre Wave Band Reflectometery Diagnostic System

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Keywords: HFSS: High Frequency Structure Simulato; VNA: Vector Network Analyser; BeO: Beryllium oxide; CHARUSAT: Charotar University of Science and Technology

ABSTRACT

The aims to present this paper to design and develop the pill box type RF vacuum window in millimetre wave used for reflectometery diagnostic system. The Pill box type vacuum window which is define the waveguide structure for handling the power launch between the antenna and transmitter and receiver. This assembly designed for the millimetre wave propagation to hold ultra-high vacuum. The analytical designed and simulation for RF window is carried out using Ansoft high frequency structure simulator (HFSS) software. Simulation of the designed vacuum window has been carried out with different material with different thickness like Kapton (63.5 and 125 microns), Mica (50 and 110 microns) and Beryllium Oxide (218 and 290 microns). Based on the availability and simulation results Kapton material with 63.5 micron thickness is utilized for transferring the microwave energy from vacuum to outer pressurized atmosphere. Simulation result shows that Kapton with 63.5 micron has return loss better than -20 dB and insertion loss less than 0.20 dB in the operating frequency band of 26 GHz to 36 GHz (Ka-band). Moreover, measured results are well matches with the simulation result. In this paper the system realization, assembly, helium leak rate and cold test measurement of RF window also carried out.

Introduction

A reflectometry diagnostic system based on the FMCW RADAR principle operating at 26 GHz to 36 GHz is designed and developed for the measurement of plasma density profile with ultra-fast time resolution. Block diagram of the same is shown in the Figure 1. Various microwave passive components are developed for the reflectometry system like filters, power divider, antenna and so on [1-3]. The RF window is one of the most important part in microwave application where a separation is required between high vacuum environment and outside atmosphere [4]. In our reflectometry diagnostic system designed for Aditya-U tokamak needs two vacuum windows first between horn antenna and amplifier (transmitter side) and second between horn antenna and low noise amplifier (receiver side). The design requirement of the vacuum window are it should be transparent to the flow of RF energy, window material should have low loss tangent and mechanical size should be as per the Ka-band waveguide WR-28 size (7.11 x 3.56 mm). Various materials can be utilized in the design of vacuum window like CVD-diamond, Beryllium oxide (BeO), mica film and Alumina [5-7]. Based on the availability and simulation results pill-box vacuum window with Kapton material and 63.5 micron thickness is designed, fabricated and tested.

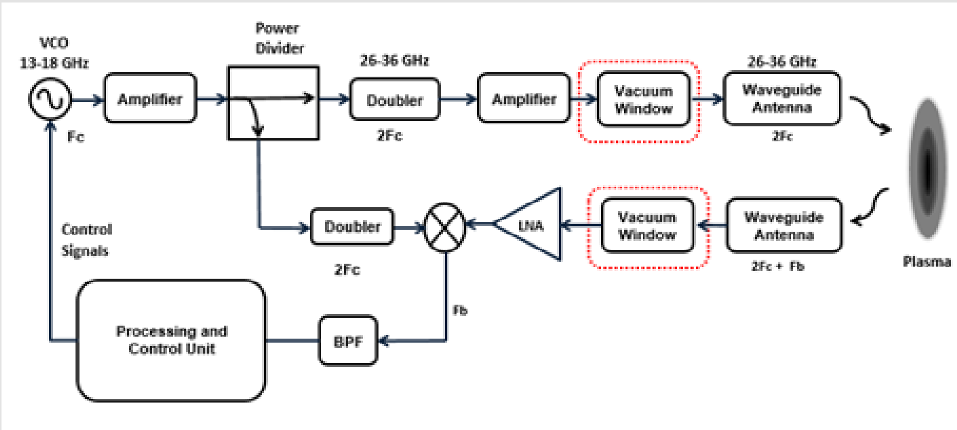

Figure 1: Block diagram of reflectometry diagnostic system.

Design and Simulation

Initially, design, simulation and optimization of the pill-box vacuum window was carried out using high-performance 3D EM analysis software CST. Designed Vacuum window assembly and cross section view is as shown in Figures 2a & 2b respectively. The fabricated vacuum window has CF16 flange end on one side and rectangular waveguide end-flange connection on the other side. Simulation of the vacuum window is carried out with various dielectric material with different thickness like Kapton (63.5 and 125 microns), Mica (50 and 110 microns) and Beryllium Oxide (218 and 290 microns). Based on the availability and simulation results Kapton material with 63.5-micron thickness is utilized in the final model. In the fabricated vacuum window special gasket with CNC milled recessions for holding Gold and Molybdenum foil gaskets is utilized, which is suitable for dielectric window material.

The simulation results of the vacuum window with various dielectric material with different thickness is shown in the Figure 3 and the values are also tabulated in (Table 1). Moreover, Electric fields distributions in the vacuum window is shown in the Figure 3b. As per the simulation results, mica with 50-micron thickness is the most deserving candidate for vacuum window design, which has returns loss more than 24 dB and the insertion loss is 0.7 dB within the desired operating frequency band of 26 GHz to 36 GHz. However, based on the availability Kapton with 63.5 micron thickness is utilized for final design, which has simulation returns loss more than 21 dB and the insertion loss better than 0.3 dB within the desired operating frequency band of 26 GHz to 36 GHz. In order to meet the requirements of the vacuum environment, the pill-box vacuum window was fabricated using the material 304L stainless steel.

Table 1: Obtained simulation results of pill-box vacuum window.

Material	Thickness	Return Loss @ 32 GHz	Insertion Loss @ 32 GHz
Kapton	125 microns	-18.6 dB	-0.17 dB
Kapton	63.5 microns	-23.5 dB	-0.10 dB
Mica	50 microns	-30 dB	-0.098 dB
Mica	110 microns	-28.3 dB	-0.096 dB
Beryllium Oxide	218 microns	-9.48 dB	-2.86 dB
Beryllium Oxide	290 microns	-9.41 dB	-2.84 dB

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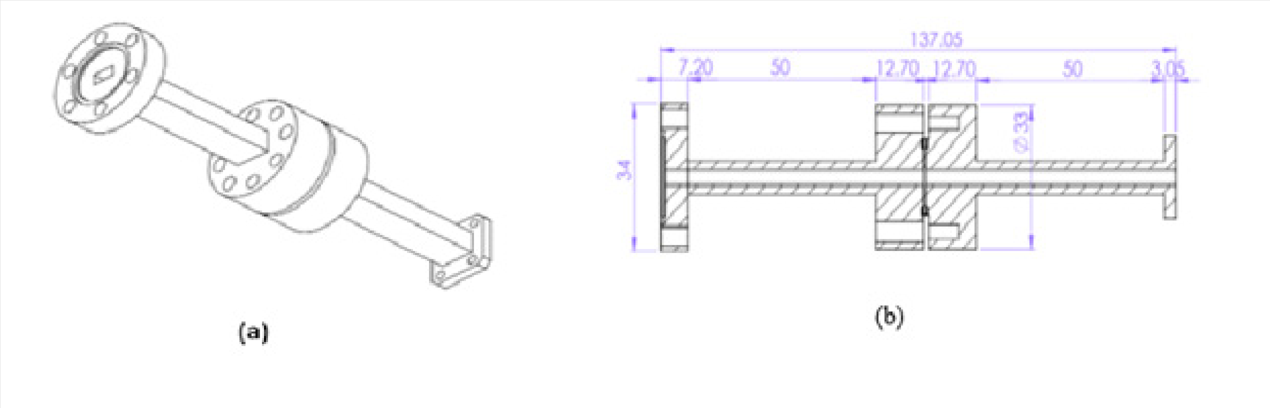

Figure 2: Vacuum window

a. Assembly and

b. Cross section view.

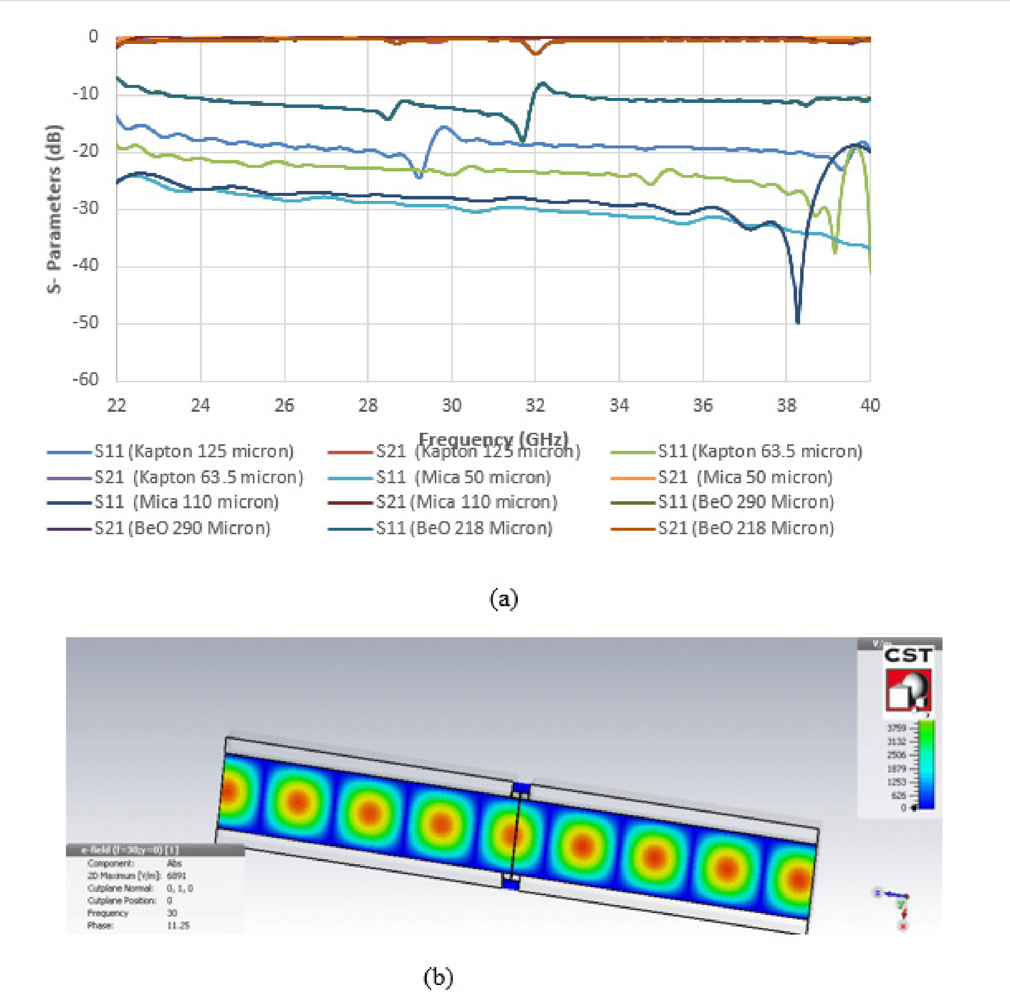

Figure 3:

a. Simulation results of vacuum window with different dielectric material and

b. Electric fields distributions in the vacuum window.

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Results and Discussion

Photograph of the fabricated vacuum window is as shown in the Figure 4. The size of the pill-box vacuum window is 137.05 x 34 mm. The leak rate of the designed vacuum window is about 5×10^{-12} mbar l/s for 10 min after spraying helium gas as shown in Figure 5. RF Testing of the vacuum is carried out using a vector network analyser (VNA) of Keysight N5245A. The simulation and measurement results of the vacuum window is as shown in Figure 6. Measurement results are well matches with the simulation results. The measurement results shows return loss more than 15 dB and an insertion loss better than 0.9 dB. It has been observed that the design vacuum window is transparent to RF energy and satisfies the criteria of vacuum environments.

Figure 4: Photograph of the fabricated vacuum window.

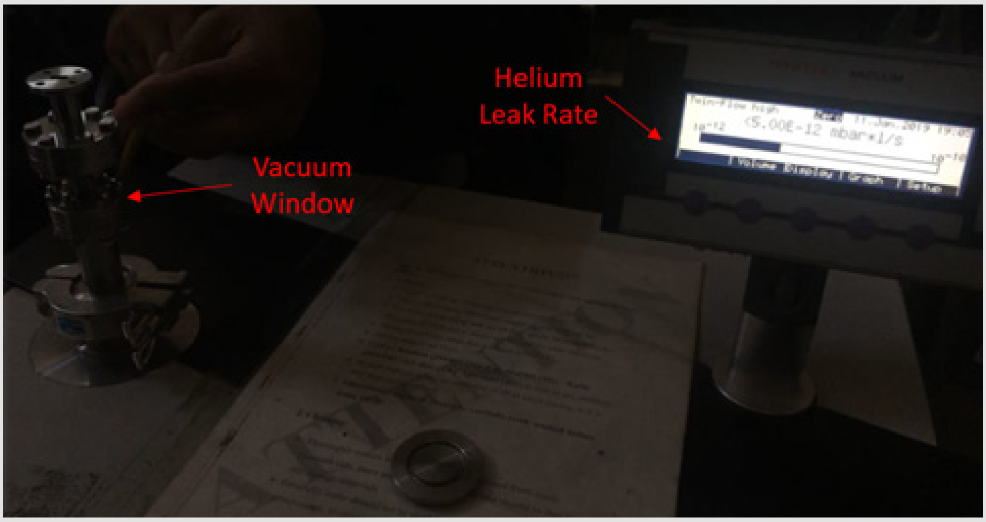

Figure 5: Helium leak rate testing of designed vacuum window.

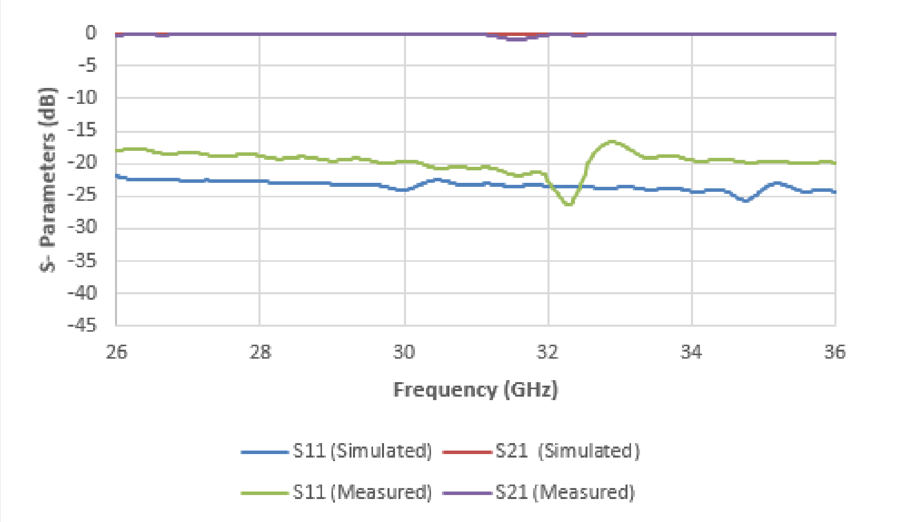

Figure 6: Simulated and measured S-parameter results of the Vacuum window Kapton (63.5 micron (thickness)).

Conclusion

A Kapton based pill-box vacuum window is presented in the paper. Here, simulation of the vacuum window is carried out with different material with different thickness but considering the availability and simulation results final vacuum window is fabricated using Kapton dielectric material with 50 micron thickness. To meet the requirements of the vacuum environments, the material used for fabrication is 304L stainless steel and gaskets used is of Gold & Molybdenum foil. Furthermore, the leak test is carried out by spraying helium gas and observing leak rate, leak rate was about 5×10^{-12} mbar l/s. To verify the RF performance, testing of the vacuum window is carried out using VNA, measured result shows return loss more than 15 dB and an insertion loss better than 0.9 dB. The proposed window is integratable in our reflectometry diagnostic system. Moreover, it is also a good candidate for other Ka-band applications.

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