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Design of a multilayer output window for a 372 GHz gyro-TWA

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***Abstract*—An output window for application in a gyrotron traveling-wave amplifier (gyro-TWA) operating at a center frequency of 372 GHz is designed and simulated. The window is based on the multilayer design and has the requirement of greater than -30 dB reflection over 24 GHz bandwidth.**

Keywords—output window; gyrotron traveling-wave amplifier; microwave window;

I. Introduction

The gyrotron-travelling wave amplifier (gyro-TWA) excels in the ability to output high power microwave over the millimetre and sub-millimetre ranges. Increasingly high power microwave amplifiers operating in these wavelength ranges are in demand due to their applications such as: dynamic nuclear polarization, electron paramagnetic resonance, high resolution radars and telecommunications. Recently, both a gyrotron-backward wave oscillator (gyro-BWO) [1] and a gyro-TWA have been developed at The University of Strathclyde. The former has achieved ~12 kW output power over 88 to 102 GHz and the later is calculated to output around 5 kW power over 90 to 100 GHz. These are based on using a helically corrugated interaction region [2] driven by a cusp electron gun [3] with an input electron beam at 40 kV, 1.5 A. Based on the previous millimetre wave gyro-TWA a higher frequency, ~372 GHz, gyro-TWA is being designed. These types of amplifiers require many components which have to meet strict criteria such as: low, < -30 dB, microwave reflection over a broad bandwidth of 24 GHz and be Ultra High Vacuum (UHV) compatible. Such components include an input coupler [4], microwave reflector [5], elliptical polariser [6], interaction region [7], output launcher [8] and microwave window. In this paper the terahertz wave window at the output of the amplifier is studied.

The function of the window is to seal the ultra-high vacuum inside the amplifier from the atmosphere outside while coupling in or out microwave power with minimal reflection or absorption. Microwave windows exist in many different designs including single-disc [9], multi-disc, pillbox and Brewster [10]. The single-disc window operates over a very narrowband and the Brewster window, which is broadband, is more ideal for a plane-wave input. Therefore, the multi-disc or pillbox window can be used for this application and due to past experience the multi-disc window was chosen.

The multi-disc window, also known as multilayer, uses different layers of dielectric materials to make a maximum transmission pass-band. The central disc usually acts to seal the vacuum with a matching dielectric disc at each side, separated by a small vacuum/air gap. The setup means the system has three dielectric discs and five dielectric layers. This type of window has been realised throughout the frequency bands from X-band [11], Ka-band [12] up to W-band [13,14].

The W-band study [14] showed that improvement in window performance can be achieved if the input mode is changed from the fundamental TE_{11} to the Gaussian-like HE_{11} mode. This will act to concentrate the microwave power at the centre of the waveguide and consequently reduce the effect of radial steps in the waveguide, which can limit the lowest achievable reflection. Therefore the mode conversion will allow for easier construction of the window.

The material choice for the window is very important. It is common to use materials such as ceramics, CVD diamond, sapphire and quartz in a microwave vacuum electronic device (MVED). Ceramics are commonly used due to their low cost, mechanical strength and capability of being brazed, although they have a relatively large loss tangent and dielectric constant.

II. Simulation

The multilayer design could be speedily and easily solved through the mode-matching method. Simulations could be solved in a few minutes and thus leading to fast optimisation of the window geometry. The window geometry is detailed in Fig. 1.

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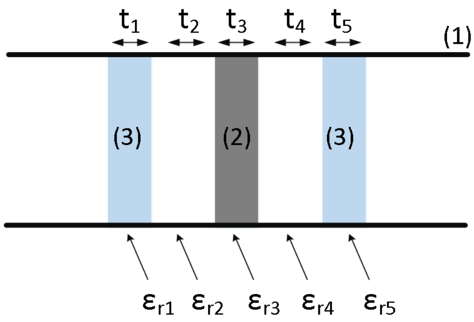

Fig. 1. Multilayer windwo geometery detailing (1) waveguide, (2) dielectric disc and (3) matching dielectric discs.

Alumina 99.4% with purity was chosen as the material for the central disc (2) due to its ease of brazing, therefore Er3 = 9.4. The matching discs (3) were chose to be quartz as this was known from past studies to be able to achieve the required bandwidth, so Er1=Er2=3.75. The waveguide diameter was set to be 5 mm, a value that could be adjusted depending on the available input source. In this idealistic setup, with the diameters of the discs and waveguide constant, the input microwave mode was TE_{11} mode as this could be readily solved through the mode-matching method. However, with the constant diameter this should be a close match to the HE_{11} mode reflection with negligible discrepancies. The optimised reflection coefficient was found and is detailed in Fig. 2.

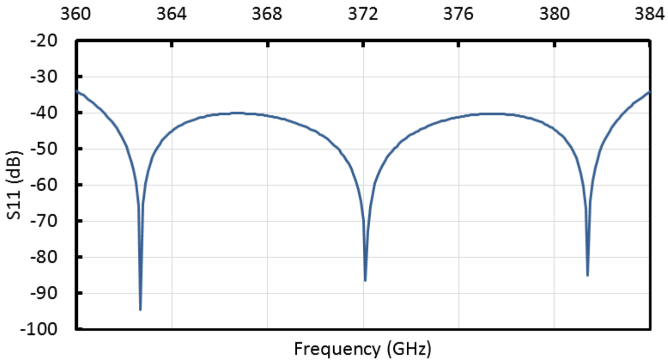

Fig. 2. Multilayer windwo simulation result

This simulation shows that the optimised thicknesses of the dielectric layers are T3 = 0.809 mm, T2 = T4 = 0.056 mm, T1 = T5 = 0.255 mm. The optimised structure shows that the vacuum gap is particularly small and will make construction difficult due to the dependence on accurate machining. Further simulations using the output from a mode converting horn will be made using a 3D simulation software such as CST Microwave Studio. Detailed simulations, as well as the tolerance analysis on the dielectric layers will be presented.

III. Conclusion

A multilayer window operate at 372 GHz with a bandwidth of 24 GHz is presented. Initial simulations have shown that the required better than -30 dB reflection is achievable over a greater than 10% bandwidth. Further investigation is currently underway and will be presented.

REFERENCES

[1] W. He, C. R. Donaldson, L. Zhang, et al., “High power wideband gyrotron backward wave oscillator operating towards the terahertz region,” *Phys. Rev. Lett.*, 110, 165101, 2013.

[2] V.L. Bratman, A.W. Cross, G.G. Denisov, et al., “High-gain wide-band gyrotron traveling wave amplifier with a helically corrugated waveguide,” *Phys. Rev. Lett*., 84, pp. 2746-2749, 2000.

[3] C. R. Donaldson, W. He, A.W. Cross, et al., “A cusp electron gun for millimeter wave gyro-devices”, *Appl. Phys. Lett.,* 96, 141501, 2010.

[4] L. Zhang, W. He, C. R. Donaldson, et al., “Design and measurement of a broadband sidewall coupler for a W-band gyro-TWA,” *IEEE Trans. Microw. Theory Techn.*, 63, pp. 3183–3190, 2015.

[5] L. Zhang, W. He, C. R. Donaldson, and A. W. Cross, “Bandwidth Study of the Microwave Reflectors with Rectangular Corrugations,” *J Infrared Milli Terahz Waves*, 37, pp. 846-856, 2016.

[6] L. Zhang, C.R. Donaldson, and W. He, “Design and measurement of a polarization converter based on a truncated circular waveguide,” *J. Phys. D: Appl. Phys*., 45, 345103, 2012.

[7] L. Zhang W. He, K. Ronald., et al., “Multi-mode coupling wave theory for helically corrugated waveguide,” *IEEE Trans. Microw. Theory Techn.*, 60, pp. 1–7, 2012.

[8] P. McElhinney, C.R. Donaldson, L. Zhang, and W. He, “A high directivity broadband corrugated horn for W-band gyro-devices, ” *IEEE Trans. Antennas Propag.* 61, pp. 1453-1456, 2013.

[9] M. E. Hill, R. S. Callin and D. H. Whittum, “High-Power Vacuum Window in WR10,” *IEEE Trans. Microw. Theory Techn*., 49, pp. 994 – 995, 2001.

[10] Y. Zhang, L. Zhang, W. He, et al., “Design and measurement of a W-band Brewster window,” *IEEE Trans. Microw Compon Lett*, 25, pp. 826-828, 2015.

[11] C. G. Whyte, K. Ronald, A.R. Young, et al., “Wideband gyro-amplifiers,” *IEEE Trans. Plasma Sci*., 40, pp. 1303–1310, 2012.

[12] V. L. Bratman, G.G. Denisov, V.N. Manuilov, et al., “New experimental results on the gyro-TWT with a helically grooved waveguide,” in *Proc. 3rd Int. Conf. on Microw. Millim. Wave Technol*., pp. 90–93, 2002.

[13] C. R. Donaldson, W. He, L. Zhang and A. W. Cross, "A W-band multi-layer microwave window for pulsed operation of gyro-devices," *IEEE Microw. Wireless Compon. Lett*., 3, pp. 237-239, 2013.

[14] C. R. Donaldson, P. McElhinney, L. Zhang, and W. He, “Wide-band HE_{11} mode terahertz wave windows for gyro-amplifiers, ” *IEEE Trans. THz Sci. Technol.*, 6, pp. 108-112, 2016.