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Integrated Micromachined Waveguide Absorbers at 220 – 325 GHz

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Abstract—This paper presents the characterization of integrated micromachined waveguide absorbers in the frequency band of 220 to 325 GHz. Tapered absorber wedges were cut out of four different commercially available semi-rigid absorber materials and inserted in a backshorted micromachined waveguide cavity for characterization. The absorption properties of these materials are only specified at 10 GHz, and their absorption behavior above 100 GHz was so far unknown. To study the effect of the geometry of the absorber wedges, the return loss of different absorber lengths and tapering angles was investigated. The results show that longer and sharper sloped wedges from the material specified with the lowest dielectric constant, but not the highest specified absorption, are superior over other geometries and absorber materials. The best results were achieved for 5 mm long absorbers with a tapering angle of 23° in the material RS-4200 from the supplier Resin Systems, having a return loss of better than 13 dB over the whole frequency range of 220 to 325 GHz. These absorber wedges are intended to be used as matched loads in micromachined waveguide circuits. To the best of our knowledge, this is the first publication characterizing such micromachined waveguide absorbers.

Index Terms—microwave absorbers, THz, micromachined waveguides, millimeter-wave, submillimeter-wave, matched load

I. INTRODUCTION

Microwave absorbers are widely used in microwave engineering, in particular for terminating ports with a matched load [1]. The main requirements on such absorbers in rectangular waveguides is low return loss and, in particular for integrated waveguide systems, small size. The return loss is determined by reflections from air-to-absorber interface and those from the waveguide backshort, which are attenuated by the absorbing material. In order to keep the former low, different shapes, in particular tapered geometries, are widely employed [2]. For commercially-available absorbing materials, the attenuation per unit length, permittivity and permeability are specified by the suppliers at RF or lower microwave frequencies, but little is known about the behaviour of such materials at frequencies above 100 GHz, and in particular not for the frequency range of 220 to 325 GHz as investigated in this paper. The dimensions of the waveguide in this frequency range add to the challenge of manufacturing tapered absorber shapes. 3D-printing techniques have recently been employed to fabricate absorber structures at 8 to 12 GHz [3], but are limited in frequency by the resolution of the 3D printer. Matched loads realised by inserting absorbers into metal rectangular waveguides have previously been used for calibration up to 750 GHz [4]. To the best of our knowledge, there are only two

Fig. 1. (a) 3D cross-section view of the waveguide cavity and (b) top view of waveguide cavity with inserted absorber

prior publications using a micromachined waveguide absorber based on a tapered absorber wedge which is inserted into a micromachined waveguide, utilized for terminating the isolated port of hybrid couplers fabricated in a micromachined E-plane split waveguide technology, operating at 500 to 600 GHz [5] and 340 GHz [6]. In both publications, however, no characterization data of the used absorbers or any information on the absorber geometries is given. This paper investigates wedge absorbers integrated into a micromachined waveguide at 220 to 325 GHz, by comparing four different materials and different absorber geometries. To the best of our knowledge, this is the first publication reporting on the characterization of absorbers integrated in micromachined waveguides in this

Fig. 2. Microscope pictures of (a) absorber wedge with $l_4 = 5$ mm and $\phi_1 = 23^\circ$, (b) the empty waveguide cavity and (c) the waveguide cavity with inserted absorber wedge

frequency range.

II. DESIGN

The absorber design concept is shown in Figure 1. The micromachined waveguide stub broadens towards its end and is designed for housing a solid absorber material.

The main geometrical parameters are the absorber length, which affects reflections from the backshort of the waveguide, and the slope of the tapering, which determines the reflections created at the air to absorber interface. In this paper, measurements of the waveguide backshort reflection are used as reference, to demonstrate the performance of the realised absorber shapes. The tapering is done in the H-plane.

Three different resin-based microwave absorbing materials from Resin Systems (RS-4200, RS-4600, RS-4800) are investigated along with a filled silicone rubber sheet material from Cuming Microwave (RGD-S-124). The dielectric constants, loss tangents and the attenuation of the materials, according to information by the manufacturers (where available), are summarized at 10 GHz in Table I. The absorber sheet thickness for all materials is $250 \mu\text{m}$, where the height of the waveguide itself is $275 \mu\text{m}$, thus filling the waveguide height to 91 %.

The solid absorbing materials are cut from the absorber sheets using a Graphtec cutting plotter fitted with a cemented Carbide blade. This method provides a simple, low cost solution to creating sub-millimeter geometries in a chosen material, and avoids the need for any chemical/thermal processing, which may affect the RF performance of the material. As the materials investigated here are semi-rigid and all of different

TABLE I
MATERIAL PROPERTIES OF THE FOUR COMMERCIALLY AVAILABLE ABSORBER MATERIALS TESTED IN THE MICROMACHINED WAVEGUIDE CAVITIES

Material	ϵ_r	attenuation (dB/mm)	$\tan \delta$	max. operating temperature ($^\circ\text{C}$)
RS-4200	9.7	1.26	0.05	176
RS-4600	21.0	4.53	0.02	176
RS-4800	23.6	6.30	0.03	176
RGD-S-124	—	6.90	—	200

TABLE II
ABSORBER DESIGN PARAMETERS

angle		length	
ϕ_1	23°	l_1	2 mm
ϕ_2	30°	l_2	3 mm
ϕ_3	40°	l_3	4 mm
ϕ_4	60°	l_4	5 mm

rigidity, the cutting procedure was carefully optimised to ensure accuracy of the resulting shapes. Four different shape lengths l_i and four different taper angles ϕ_j are investigated in this paper, with the parameter variations given in Table II.

Figure 2a shows a microscopic picture of a cut absorber wedge with $l_4 = 5$ mm and $\phi_1 = 23^\circ$.

The backshort waveguide cavities are designed to house the individual absorber wedges. The tip of the absorber wedge is placed at the reference plane of the waveguide cavity and thus the end of the tapering of the absorber wedge where the absorber fills the waveguide cavity completely is closer to the reference plane for absorber wedges with higher taper angles.

The absorbers are integrated in a low-loss micromachined waveguide technology available at KTH [7] consisting of a silicon-wafer triple stack in a double H-plane split configuration, with the central wafer being $275 \mu\text{m}$ thick and etched by deep-reactive ion etching. The waveguide height is only 66 % of the full-height ($432 \mu\text{m}$). The waveguides are metallized with $1 \mu\text{m}$ of gold. Before the final assembly by chip-level thermo-compression bonding, the absorber material is manually inserted into the waveguide. Figure 2b shows the empty waveguide cavity and Figure 2c after the absorber wedge is manually placed inside the waveguide cavity. A reduced thickness material was used to ensure the insertion of the material did not prevent proper connection between the sidewalls and roof of the H-plane split waveguide. Thermo-compression bonding performed at 200°C , which is within or not significantly outside the material specifications for the operation temperature range of the absorber materials given by the manufacturers and listed in Table I. In addition, temperature tests of the absorber materials have confirmed that there is no significant change of the tapered absorber geometry when exposed to temperature treatment of 200°C for several hours.

III. MEASUREMENT AND RESULTS

The return loss of the waveguide absorbers was measured using a Rohde & Schwarz ZVA 24 Vector Network Analyzer with two Rohde & Schwarz ZC330 TxRx extension heads for 220 to 325 GHz. A Thru-Reflect-Line (TRL) calibration was performed with a tailor-made micromachined waveguide on-chip TRL calibration kit, to move the reference plane as close as possible to the absorber into the micromachined waveguide.

Figures 3a and 3b show the measured reflection coefficient for all materials for absorbers with cavity length l_4 for the two different tapering angles ϕ_1 and ϕ_3 . The material with the lowest dielectric constant, RS-4200, is expected to give the best results since it has the lowest reflections from the air to absorber interface in the waveguide. This is confirmed in both configurations, by the measured return loss of better than 13 dB through the whole frequency band. Figure 3b shows the measured return loss for angle $\phi_3 = 40^\circ$ which demonstrates the superior absorbing behaviour of the stronger tapered wedge with $\phi_1 = 23^\circ$.

Figure 4a shows the return loss for the best material (RS-4200), when varying the length of the absorber. The length $l_4 = 5$ mm results in the lowest return loss. There is a good correlation between the return loss and the length with the exception of l_3 , which might be caused by inaccurate placing of the absorber in the waveguide. Figure 4b shows the return loss dependency on the tapering angle which also shows excellent correlation of the return loss to the degree of tapering. For comparison Figures 5a and 5b show the corresponding return loss for RGD-S-124.

IV. CONCLUSION

This paper presented the characterisation of various compact, integrated micromachined waveguide loads which were implemented using tapered wedge shapes, cut from planar sheets of commercially available absorbing material. Four different materials, unspecified above 100 GHz, were investigated for the frequency range 220 – 330 GHz. It was clearly shown that absorber shapes with shallow, long tapers offer better performance than shapes of the equivalent size with short, sharp tapers and longer filled sections. Furthermore, it was shown by the measurement results that materials with a lower permittivity (and hence lower impedance mismatch) are preferable over those with higher levels of attenuation per unit length.

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Fig. 3. Measured reflection coefficient for waveguide cavities filled with absorbers with cavity length $l_4 = 5$ mm and angle (a) $\phi_1 = 23^\circ$ and (b) $\phi_3 = 40^\circ$ with empty waveguide cavity as reference

Fig. 4. Measured reflection coefficient for waveguide cavities filled with RS-4200 absorbers for (b) different angles with cavity length $l_4 = 5$ mm and empty waveguide cavity as reference and (a) different lengths with absorber angle $\phi_1 = 23^\circ$

Fig. 5. Measured reflection coefficient for waveguide cavities filled with RGD-S-124 absorbers for (b) different angles with cavity length $l_4 = 5$ mm and empty waveguide cavity as reference and (a) different lengths with absorber angle $\phi_1 = 23^\circ$