Microstrip-to-Waveguide Transition with Stepped E-plane Probe for G-band Photodetectors

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***Abstract*—We present a broadband microstrip-to-WR5 transition with stepped E-plane probe. Back-to-back transition with aluminum package is fabricated and measured, and low insertion loss below 1.5 dB is estimated for single microstrip-to-WR5 transition over 140-220 GHz.**

***Keywords*—Microstrip, rectangular waveguide, E-plane probe, WR5-outputs, back-to-back packaging, G-band.**

I. Introduction

Photodiodes (PDs) working at millimeter wave (MMW) band have attracted enormous interests, including wireless communications [1], spectroscopic sensing [2], and imaging systems [3]. The performance of PDs at frequencies above 145 GHz is limited by the 0.8 mm RF connectors [4]. Therefore, PD modules with standard waveguide outputs are desirable, in which transition between waveguides and planar transmission lines is indispensable. In previous studies reported at D-band, the coplanar waveguide to rectangular waveguide transition using wire bonding probe exhibits an insertion loss (IL) of 1.5 dB [5], and the transition using metal ridge shows an IL of 2 dB [6], both suffering from poor repeatability and large loss.

In this work, we propose a microstrip-to-waveguide transition using stepped E-plane probe for PD modules working at G-band (140-220 GHz). Impedance matching is achieved by adjusting the width of microstrip, securing wideband operation with low insertion loss. The proposed structure is simulated to exhibit an IL of 0.5 dB. An aluminum packaged back-to-back transition is fabricated, and the measurement shows smooth transition over the entire G-band, together with an IL less than 1.5 dB for single microstrip-to-waveguide transition.

II. E-plane Probe Design

The E-plane probe is shown in Fig. 1(a), in which the microstrip plane is perpendicular to the propagation direction of the electromagnetic wave in the waveguide. Compared with the H-plane probe, it introduces less discontinuity. We adopt 127-μm-thick quartz substrate for its low dielectric constant of 3.68, which is essential to decrease the dielectric loss at high frequencies over 140-220 GHz. A finite element method (FEM) based full 3-D electro-magnetic simulation is shown in Fig. 1(b), where the microstrip is enclosed by an air box with the dimension of standard WR-5 waveguide (a = 1295.4 μm, b = 647.7 μm). A window with height h = 400 μm is opened parallel to the H-plane of the waveguide.

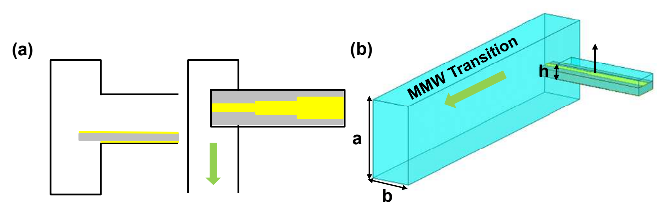

Fig. 1. (a) E-plane probe structure. (b) 3-D view of microwave-to-waveguide transition.

The window height is so chosen as to suppress higher-order modes. As the equivalent impedance of the WR-5 waveguide at the center frequency of 180 GHz is 320 Ω, a stepped probe shown in Fig. 2(a) is employed to smoothly transform the impedance of the microstrip to 50 Ω with probe width W_1 = 110 μm, W_2 = 150 μm, and W_3 = 180 μm, respectively. As illustrated in Fig. 2(b), the probe is located λ/4 from the short-end to convert the termination from short to open, so as to ensure maximum electric field for improved coupling efficiency. The optimized distance to short-end is L_s = 440 μm, while the probe length inserted into the waveguide is set to L_p = 340 μm.

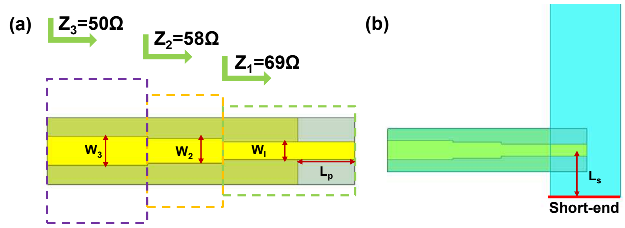

Fig. 2. (a) Top view of stepped probe. (b) Relative position of the probe and the waveguide.

In order to validate the proposed design, a back-to-back microstrip-to-waveguide transition is modeled and simulated as shown in Fig. 3(a). The aluminum WR-5 waveguide package is designed to accommodate the probe in Fig. 3(b). As shown in Fig. 3(c), the simulation results with and without the aluminum packages exhibit only slight differences. The return loss (RL) is at least 10 dB, together with about 1 dB insertion loss for the back-to-back transition, corresponding to less than 0.5 dB insertion loss for a single probe-to-waveguide transition at G-band.

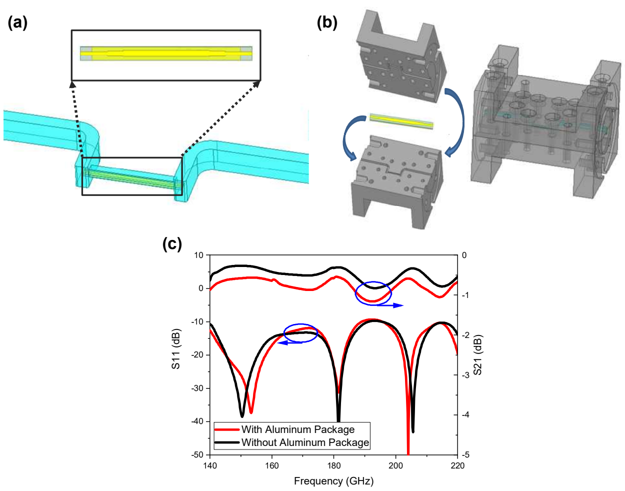

Fig. 3. (a) Back-to-back transition with air box and (b) aluminum package. (c) Simulated S-parameters of probe packages.

III. Measurement and Results

The fabricated gold-plated probe package is measured by a vector network analyzer (VNA) equipped with two calibrated WR-5 waveguide extenders, as shown in Fig. 4(a). According to the measurement results plotted in Fig. 4(b), the back-to-back transition exhibits a flat transmission, together with an RL better than 10 dB over most part of the G-band. The IL is 3 dB, corresponding to an IL of 1.5 dB at the most for a single microstrip-to-waveguide transition. The measurement and simulation results are plotted against each other in Fig. 4(c), where the slight differences are attributed to probe alignment, ground connections, and packaging tolerances.

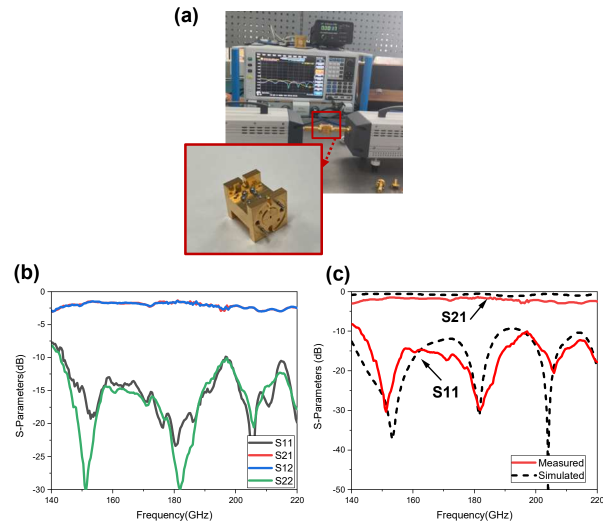

Fig. 4. (a) Experimental setup of measurement system. (b) Measured S-parameters. (c) Measurement and simulation results of the back-to-back probe package.

IV. Conclusion

We have demonstrated a G-band microstrip-to-WR-5 waveguide transition employing a stepped-impedance E-plane probe based on 127-μm-thick quartz substrate. Back-to-back transition with aluminum package is fabricated, and the measured RL is better than 10 dB together with an IL of 3 dB over the G-band. Thus microstrip-to-waveguide transition with less than 1.5 dB insertion loss is estimated. The smooth and low loss transition at such high frequencies is desirable for G-band photodiode modules with WR5-outputs.

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