Terahertz vertical transition structure based on coupling cavity

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Abstract: The paper proposed a cavity-coupled vertical transition structure working at 110 GHz. Two mode-transition units were fabricated at ends of a vertical metal cavity symmetrically, acting as two excitation ports of a waveguide. The proposed mode-transition unit was realized on a 50-μm thick quartz-substrate with via holes and double-side patterned. In this way, the vertical transition structure presented a low insertion loss at terahertz frequency. Good agreement between simulated and measured results was obtained. The simulated S_{21} of the mode-transition unit was −0.7 dB, the measured S_{21} was less than −1.3 dB. The bandwidth from 105 GHz to 116 GHz was obtained for reflection level lower than −10 dB.

Key words: terahertz vertical transition; quartz; coupling cavity

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基于耦合腔的太赫兹垂直传输结构

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摘 要： 提出了一种工作在 110 GHz 的耦合腔垂直传输结构。在垂直金属腔的两端对称地装配两个模式变换单元,作为波导的两个激励端口。模式变换单元在 50 μm 厚度石英基片上实现,该基片采用通孔结构和双面镀金工艺。因此,该垂直传输结构在太赫兹频段具有较低的插入损耗。仿真结果与测试结果拟合良好,模式变换单元的 S_{21} 仿真结果为−0.7 dB,测试结果小于−1.3 dB,在 105~116 GHz 带宽的反射系数低于−10 dB。

关键词： 太赫兹垂直传输； 石英； 耦合腔

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0 Introduction

Short-distance communication system operating at terahertz band has called for high transmitting power on compact structure[1]. High density integrated circuit with vertical transition structure, which saves a lot of space and helps increasing output power, is in great demand[2]. In order to achieve a good transmitting performance, the vertical transition structure should provide a low transition loss over a broad bandwidth with more convenient mode transformation[3].

In recent years, vertical transition techniques are widely developed in compact integration of active and passive circuits, such as through silicon-via (TSV) and low-temperature co-fired ceramic circuits(LTCC)[4–5].

Traditionally, vertical transition structures, are most commonly used in forms of via-hole, aperture-coupled and cavity-coupled[6–7]. However, a via-hole exhibits unwanted parasitic affects at high frequencies and results in a degraded performance. An aperture-coupled structure suffers from the undesirable radiation leakage with additional loss and poor isolation due to its structure character. Both of these two structures are fabricated on thin layer substrate. Neither of them can solve heat issues.

Cavity-coupled transitions, however, can be regarded as an aperture in a thick common ground plane[8]. Compared with an aperture-coupled transitions[9], the cavity-coupled type has a relatively longer distance in vertical direction and lead to a solution to the heat-dissipation problem.

In this letter, the quartz media thinning and two-sided plating technologies are used to design a low-loss, 50-μm thick vertical transition structure. A mode transition technique is utilized to accurately evaluate signal transmission path. A coupling cavity is introduced to connect with the mode transition unit. Taking the advantage of good thermal conductivity of the metal wall, high power active devices can be integrated into this architecture. This vertical transition structure exhibits a potential in power combining with low insertion loss at terahertz frequency.

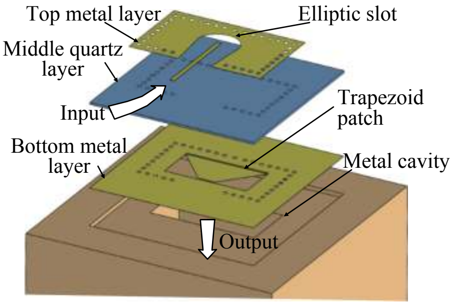
1 Design

Figure 1(a) shows the general structure of the vertical transition structure operating at terahertz band. It is composed of a rectangular waveguide WR-10 (2.54 mm ×1.27 mm) and two quartz-substrates (relative dielectric constant ε_r=3.78). Guided signal is transimitted from horizontal microstrip-line on top layer of the substrate to the vertical waveguide using a trapezoid patch. Quasi-TEM mode is transformed into TE_{10} mode. Considering the high frequency performance is affected by the thickness of the substrate, the substrate is thinned to 50 μm. As we can see from Fig.1(b) and 1(c), the elliptic slot on top layer is optimized to extend the working bandwidth. The trapezoid patch is deployed on bottom layer to guide signal vertically. The metal via holes extend the cavity walls into the substrate. It is shown in Reference[9] that smaller length L_h between the via holes provides higher efficiency of electromagnetic transition between the cavity and the microstrip-line.

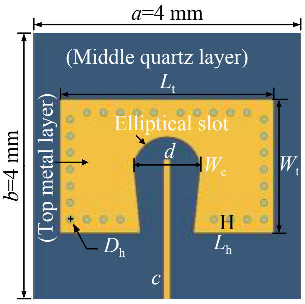
On the other side of the cavity, there is a symmetrical mode-transition unit transforming signal from cavity to microstrip-line. The use of the metal cavity increases the heat dissipation capability and makes it compatible with active integrated circuit. As we can see from the Fig.2, the 3D structure is ready to integrated with a power amplifier.

Adjusting electromagnetic field distribution of the mode-transition unit is the key factor that helps transmitting guided signal from planar transition to vertical direction. Several simulations were performed to evaluate the performance of the vertical transition structure using full-wave electromagnetic simulator HFSS. As we can see from the Fig.3, electric-field vector lines mainly lie in the slot between trapezoid patch and rectangular metal. The electric-field distribution in this unit is similar to a standard rectangular waveguide. Good transmitting performance can be predicted.

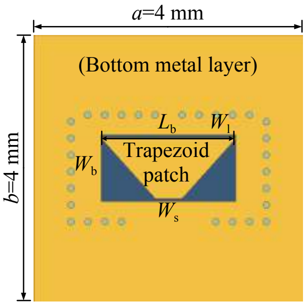
The width W_e of elliptical slot is then under investigation. As the width increases, the working band



(a) Vertical transition structure



(b) Top view



(c) Bottom view

Fig.1 General vertical transition structure

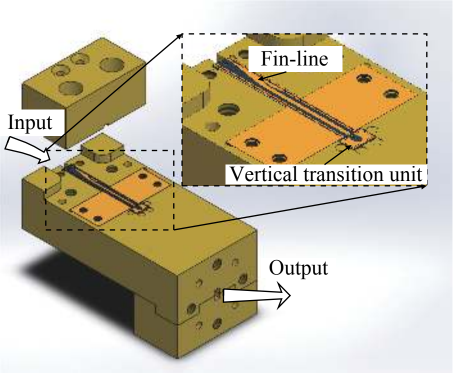


Fig.2 Designed structure of the vertical transition

width is extended. When the width W_l of trapezoid patch is changed, the transition impedance matching is affected. The larger the width W_l is, the lower the insertion loss will be. The simulation results are presented in Fig.4.

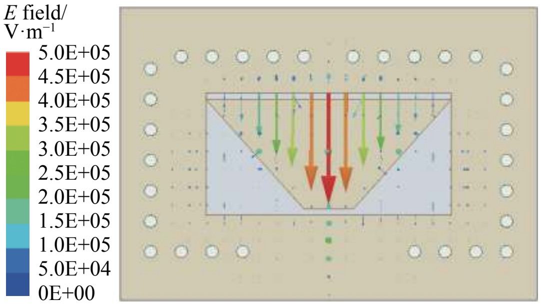
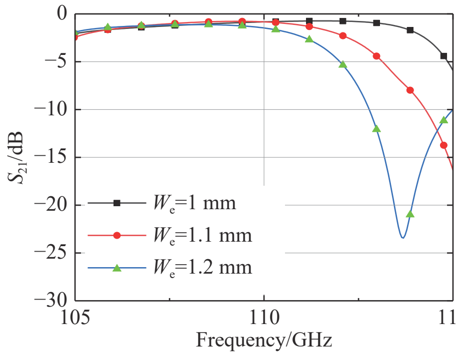
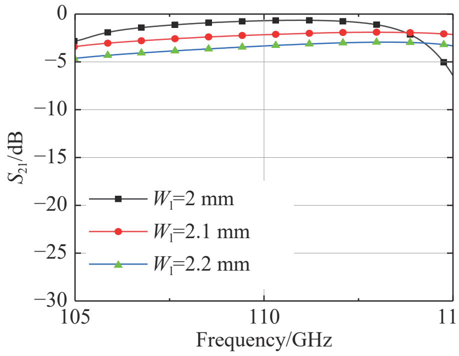


Fig.3 Electric-field distribution of mode-transition unit



(a) Elliptical width W_e



(b) Trapezoid width W_l

Fig.4 Optimization of vertical transition unit

Other than the two characters discussed above, a mass of work has been done to reach a better transition performance. For example, the length L_h between holes and the diameter D_h of the hole on quartz are designed to be 150 μm and 100 μm. Comprehensive consideration is made on basis of optimal design and engineering practice. Optimized parameters of vertical transition unit are presented in Tab.1. Photographs of the assembled structure and the fabricated mode-transition unit are shown in Fig.5.

For the convenience of testing, fin-line is used to transform signals from rectangular waveguide to vertical transition structure. Due to the discontinuity between free

Tab.1 Parameters of vertical transition unit

Parameters	Value/mm	Parameters	Value/mm
a	4	W_e	1
b	4	W_l	2
c	2.1	W_s	0.4
d	0.102	D_h	0.1
W_t	2	L_h	0.15
L_t	3.2	L_b	2
W_b	1		

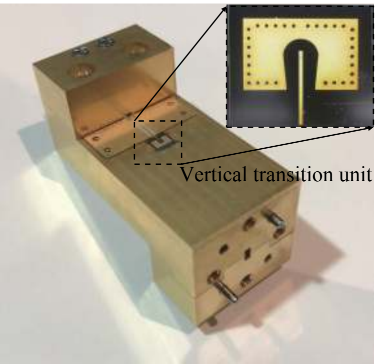
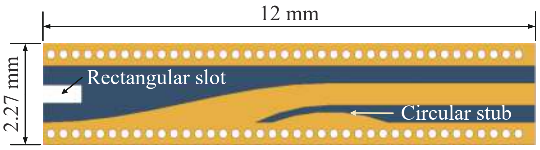
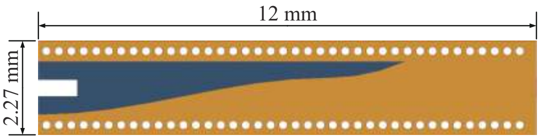


Fig.5 Photograph of the assembled structure and the fabricated mode-transition unit

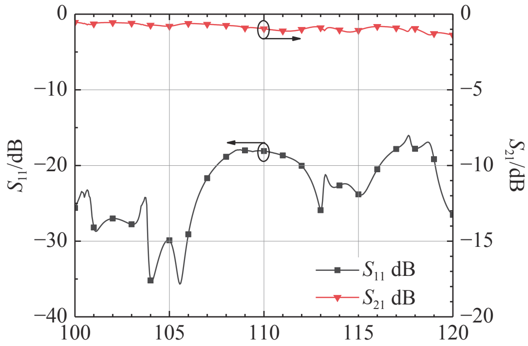
space and fin-line, a mismatch occurs when free-space waves are transformed into guided waves. A rectangle slot is added at the front end of the structure to match the input impedance. A circular tuning stub is added besides the microstrip-line to extend working bandwidth. The optimized transformation loss is below −1.1 dB and return loss is less than −15 dB in working-band. The structure is constructed on Rogers@ RT4003C with a substrate thickness of 0.203 mm. The fin-line character is shown in the Fig.6.



(a) Top view



(b) Bottom view



(c) Simulated results

Fig.6 Proposed fin-line structure

2 Measurements and results

Vertical transition structure is measured in this section. Performance of the assembled transition structure with the optimum parameters is evaluated by measurement in terahertz band. The measurement was carried out on a Keysight 8257D network analyzer.

Figure 7 shows S_{11} and S_{21} for single mode-transition unit. Simulated results show a minimum insertion loss of −0.7 dB with a bandwidth of 109−112 GHz. Measured results indicate that a bandwidth of 105−116 GHz with the return loss under −10 dB. Low insertion loss is achieved with a measured insertion loss of −1.3 dB at 110 GHz. It is 0.6 dB larger than simulation.

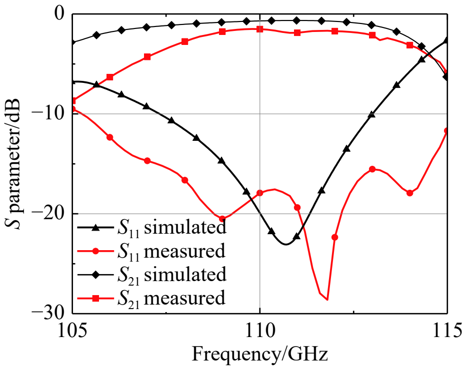


Fig.7 S parameters of mode-transition unit

Table 2 lists the performance comparisons of the quoted designs and the proposed structure. As shown in Tab.2, the proposed vertical transition structure features with a better performance at a high frequency.

Tab.2 Performance comparisons

Reference	Return loss/dB	Band width/GHz	Insertion loss/dB
[9]	−15	55-65	−1
[10]	−10	59-62	−1.79
This work	−10	105-115	−1.3

3 Conclusion

In this work, a low-loss vertical transition structure for terahertz frequency is demonstrated. The 50-μm thick quartz-substrate with via holes and double-side gold-plated is realized. The estimated transmission loss of the mode-transition structure is −1.3 dB at 110 GHz with an obtained bandwidth of 10 GHz. Combined with a 10 mm thick metal cavity, active circuit can be integrated. The vertical transition structure shows a better performance than that of the cavity-coupled counterparts, exhibiting a more promising prospect in active integrated circuit applications at terahertz frequency.

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