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硅基MEMS渐变式缝隙天线

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摘要：为了增加天线带宽，提高天线机械稳定性，改善天线性能，提出并设计制作了一种工作在35 GHz的硅基MEMS渐变式缝隙天线。针对渐变式缝隙天线在毫米波频段介电常数高、衬底极薄、易碎、不易制作等问题，利用ICP深刻蚀工艺在衬底上形成了周期性通孔阵列，从而减小了衬底有效介电常数，增加了衬底厚度，同时利用共面波导-槽线对该天线进行馈电。仿真结果表明，该天线带宽为28.2%，增益为8.7 dB。采用微机械工艺对该天线进行加工，测得其带宽为13.2%。与传统天线相比，该天线进一步提高了天线衬底的机械稳定性，增加了天线带宽，且易于集成。

关　键　词：微机电系统；渐变式缝隙天线；CPW馈电
中图分类号：TN822.4；TN823.27　　**文献标识码：**A

Tapered slot antenna on micromachined silicon substrate

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Abstract: A Tapered Slot Antenna (TSA) fed by a Coplanar Waveguide(CPW) on a high dielectric constant substrate ($\varepsilon_r=11.9$) worked at 35 GHz is presented. The performance of the TSA is sensitive to the effective thickness and electric constant of the substrate. In consideration of thin and fragile features of the high dielectric constant substrate for millimeter-wave application, a series of very closely spaced holes are formed on the substrate by using a deep etch technology, which synthesizes a localized low dielectric-constant environment and increases the effective thickness of the substrate. Otherwise, CPW-to-SLOT transitions with low insertion losses are proposed to feed this antenna. The simulation results show that the bandwidth and the gain of the antenna have been achieved 28.2% and 8.7 dB, respectively. After using micromachining technologies, the measured result shows the bandwidth is 13.2%. The difference between simulation and measurement is mainly attributed to the improvement for fabrication errors and measurement loads. This CPW-fed TSA has been expected to apply to communication systems for its easy integration with the uniplanar monolithic millimeter-wave integrated circuits.

Key words: MEMS; tapered slot antennas; CPW-fed

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1 Introduction

The prototype of the Tapered Slot Antenna (TSA), viz. the Vivaldi antenna[1-2], was proposed and developed by Gibson et al. in 1979. Thus far, the TSAs have found wide applications from communication systems and phased arrays to focal plane imaging arrays for remote sensing due to their planar design, moderately high gain , wide bandwidth ,symmetric pattern, and low sidelobe level (SLL). On the other hand, the low manufacturing cost, low sensitiveness to manufacturing error at millimeter-wave frequency, and easy connection with integrated circuits make the TSA particularly well suited for millimeter-wave applications[3-5].

However, the main problems of the TSA come from its sensitivity to the thickness and dielectric constant of the antenna substrate. An effective thickness, which represents the electrical thickness of the substrate, has been defined as: $t_{\mathrm{eff}} = t(\sqrt{\varepsilon_{\mathrm{r}}} - 1)$. For good operation of a TSA, the effective thickness should be approximately: $0.005\lambda_0 \leqslant t_{\mathrm{eff}} \leqslant 0.03\lambda_0$[2], where t is the thickness of the antenna substrate with the dielectric constant ε_r and λ_0 is the free space wavelength at the operating frequency. For substrate thickness above the upper bound of effective thickness, unwanted substrate modes develop which degrade the performance of the TSA, while antennas on thinner substrates suffer from decreased directivity. This results in a very thin supporting structure of antennas at millimeter-wave frequency on high dielectric constant substrates such as silicon or Gallium Arsenide. For a silicon carrier to a TSA, the maximum thickness ($t_{\max}$) allowed at 30 GHz is approximately 120 μm. This constraint renders the substrate thickness of the TSA impractical for millimeter-wave applications since the TSA, on such a thin substrate, is fragile.

Several solutions have been proposed in the past to alleviate this constraint. (1) The first way of improving the mechanical stability is to increase the thickness of the substrate and then selectively remove parts or nearly all of the underlying dielectric material[6-7]. If nearly all of the substrate is removed, the TSA can be suspended on a thin dielectric membrane with an effective dielectric constant of $\varepsilon_{\mathrm{r}} = 1.05$. This is easily implemented at sub mm-wave frequencies (300 GHz－3 THz), but is not as practical at mm-wave frequencies (30－300 GHz) since the membrane dimensions are large and the mechanical stability of the suspended membrane is compromised. Since the dimensions of TSA are large, selectively etching parts of the substrate under the slot will not improve the mechanical stability in nature. (2)The second method commonly used at mm-wave frequencies is the integration of the radiating antenna on a thin low dielectric substrate backed by a thick foam substrate with a dielectric constant of less than 1.1[8-9]. This is excellent at 20－100 GHz, but the thin dielectric substrate will interfere with the radiation patterns of TSA at frequencies greater than 100 GHz. (3) The third avenue is incorporation of photonic band gap structures into the substrate and closely etching an array holes to remove a portion of the underlying substrate, thereby resulting a lower quasi-static (effective) dielectric constant substrate[10]. This technique has been applied successfully using microstrip antennas.

In this paper, the third way is used to research the linear tapered slot antennas (LTSA) with a center frequency around 35 GHz on silicon substrate.

2 Design

This antenna is 4 λ_0 long with a flare angle of 12°, resulting in an aperture width of 0.8 λ_0 (Fig. 1).

The substrate is high resistivity silicon with

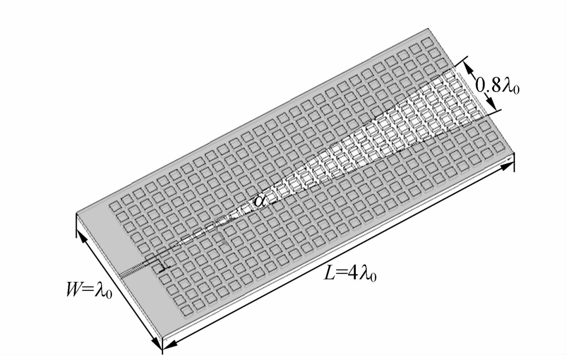


Fig. 1 Configuration for proposed LTSA

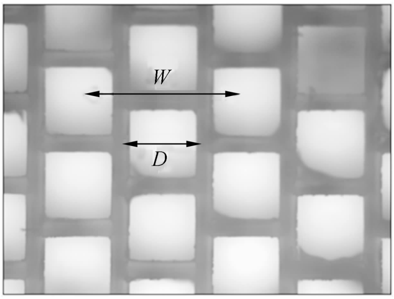


Fig. 2 Micromachined substrate of TSA

the thickness of 300 μm and a relative dielectric constant of $\varepsilon_r=11.9$. After micromachined substrate with closely array holes (Fig. 2), the effective dielectric constant is a quasi-static value, given by the volumetric average dielectric constant of the micromachined substrate, and is:

$$\varepsilon_{\mathrm{eff}}=\frac{\pi}{2}\left(\frac{D}{W}\right)^2+\varepsilon_r\left[1-\frac{\pi}{2}\left(\frac{D}{W}\right)^2\right], \qquad (1)$$

Where D and W are defined in Fig. 2, and $D=200$ μm, $W=280$ μm. For high resistivity silicon with $\varepsilon_r=11.9$, the effective dielectric constant $\varepsilon_{\mathrm{eff}}$ is equal to 3.16 for the micromachined substrate shown in Fig. 2. For a 35 GHz TSA integrated on 300 μm thick substrate, this reduction in the effective dielectric constant changes the value of $t_{\mathrm{eff}}/\lambda_0$ from 0.086 for the solid substrate to 0.027 for the micromachined substrates, placing the effective thickness just within the performance limits of Yngveson etc[2].

To reduce the system noise between antenna and other components, a kind of CPW-to-SLOT transitions with low insertion losses is proposed to feed the antenna (Fig. 3). The structure has T-type $\lambda_s/4$ slot stubs, which seems appropriate for avoiding unwanted radiation.

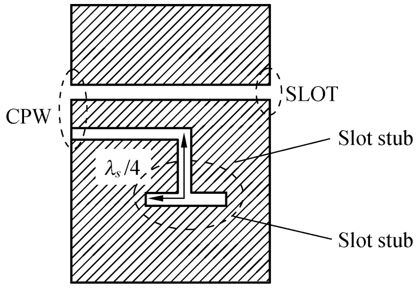


Fig. 3 Feed line of CPW-to-SLOT transition

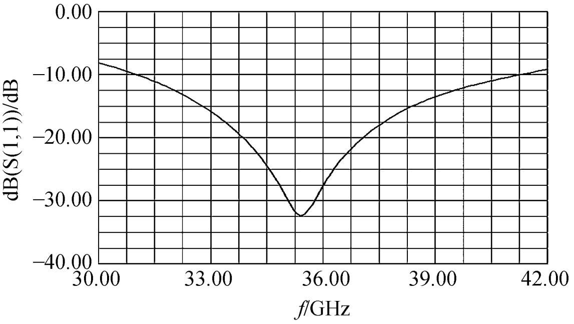
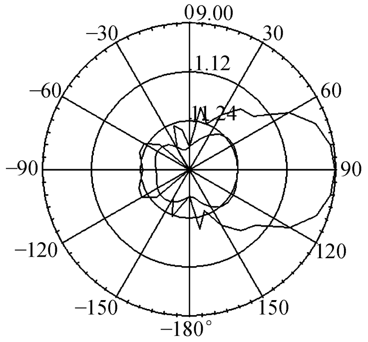
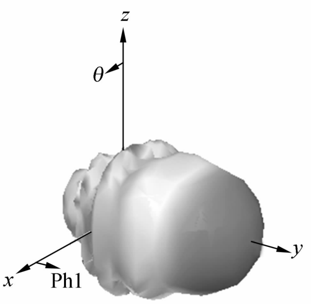


Fig. 4 Simulated return loss



(a) Two dimensional radiation pattern of TSA



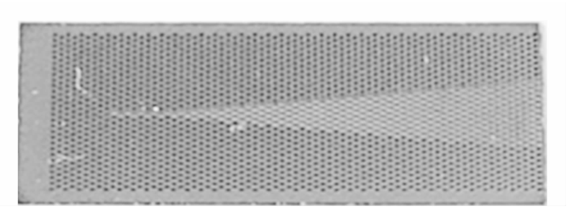
(b) Three dimensional radiation pattern of TSA

Fig. 5 Two dimensional and three dimensional radiation patterns of TSA

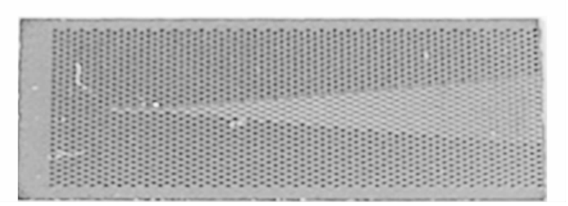
Ansoft′s High Frequency Structure Simulator 10.0(HFSS) is used in this paper to simulate the antenna. Fig. 4 shows the simulated return loss. Fig. 5 (a) and (b) show the 2-D and 3-D radiation pattern at resonance of 35.4 GHz respectively. Simulation results predict a 28.2% fractional bandwidth at 35.4 GHz with a gain of 8.7 dB.

3 Measurement

This antenna has been fabricated by using micromachining technologies. The photographs shown in Fig. 6 (a) and Fig. 6 (b) are the top and bottom views of the fabricated CPW-fed TSA respectively. Agilent E8363B network analyzer is used to measure the return loss of the antenna. And Fig. 7 has shown the measured result. It can be seen that the measured antenna is at resonance of about 34.5 GHz and have a bandwidth of 13.2%. Difference between simulation and measurement mainly attributes to the error of fabrication and measurement load.



(a)Top view



(b)Bottom view

Fig. 6 Fabricated CPW-fed TSA

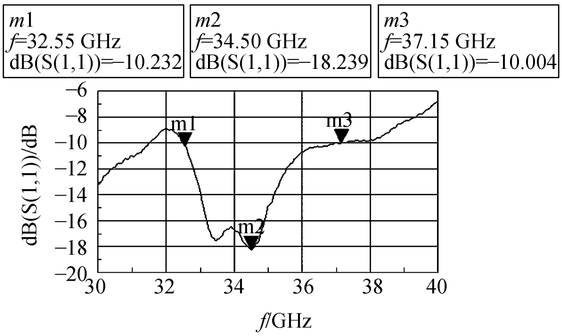


Fig. 7 Measured return loss

4 Conclusions

In conclusion, the CPW-fed TSA on silicon substrate is proposed and developed by using micromachining technologies, which solves the problems of the thin and fragile substrate of conventional TSA. Deep etching technology is used to form a series of very closely spaced holes, which synthesizes a localized low dielectric-constant environment and increases the effective thickness of the substrate. After fabrication and measurement it can achieve bandwidth of 13.2% with resonance of about 34.5 GHz. Compared with other MEMS antenna and conventional TSA, it can achieve wide, bandwidth and be easy to integrate with other components.

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