Plate-Laminated Corporate-Feed Slotted Waveguide Array Antenna at 350-GHz Band by Silicon Process

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***Abstract*—A corporate feed slotted waveguide array antenna with broadband characteristics in term of gain in the 350 GHz band is achieved by measurement for the first time. The etching accuracy for thin laminated plates of the diffusion bonding process with conventional chemical etching is limited to ±20μm. This limits the use of this process for antenna fabrication in the submillimeter wave band where the fabrication tolerances are very severe. To improve the etching accuracy of the thin laminated plates, a new fabrication process has been developed. Each silicon wafer is etched by DRIE (deep reactive ion etcher) and is plated by gold on the surface. This new fabrication process provides better fabrication tolerances about ±5 μm using wafer bond aligner. The thin laminated wafers are then bonded with the diffusion bonding process under high temperature and high pressure. To validate the proposed antenna concepts, an antenna prototype has been designed and fabricated in the 350 GHz band. The 3dB-down gain bandwidth is about 44.6 GHz by this silicon process while it was about 15GHz by the conventional process using metal plates in measurement.**

Index Terms — Submillimeter wave antennas, corporate feed waveguide, slotted waveguide array, Silicon process, DRIE (deep reactive ion etcher), Diffusion bonding process.

1. Introduction

Over the last three decades data rates of wireless communication systems have doubled every 18 months (Edholm's Law of Bandwidth 0). With this trend we will arrive soon to the capacity limits of wired connections such as optic fibers. The frequency bands below 100 GHz are already congested and to meet this high demand of data rate, it is necessary to exploit the submillimeter wave band of the electromagnetic spectrum that is not exploited yet [2].

Developing antennas in this frequency band requires not only new antenna configurations but also new fabrication processes to cope with the severe fabrication tolerances. The diffusion bonding process with chemical etching developed by the authors [3] is a suitable technology for millimeter frequency band were several antennas have been successfully demonstrated up to 120 GHz [5]. The etching accuracy for the thin laminated copper plates is ± 20 μm. This fabrication tolerance is not suitable at all for higher frequency bands such as submillimeter wave band. A trial fabrication by the authors at 350 GHz with this fabrication process showed significant ripples in the antenna gain curve and increasing level of reflections [5].

In this paper the broadband characteristic of a corporate feed slotted waveguide array antenna operating in the submillimeter wave band at 350 GHz is demonstrated by measurement for the first time. The antenna is fabricated by silicon process where each silicon wafer is etched by DRIE and is plated by gold on the surface. These laminated wafers are laminated by wafer bond aligner with about ±5μm tolerances and are then bonded in a vacuum chamber under high pressure and high temperature. This paper is organized as following. In section II the antenna configuration is described. Section III shows the measured results. A conclusion is drawn at the end of the paper.

2. Antenna configuration

A 3D view of the antenna structure is shown in Fig. 1.

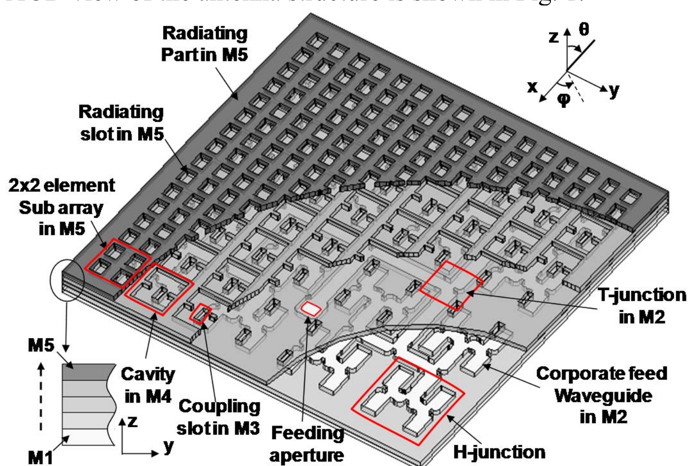

Fig. 1. Corporate-feed slotted waveguide array antenna.

The double-layer antenna is composed of two parts; *i)* a corporate feeding network in the lower layer; *ii)* a radiating part which is an array of 16×16 radiating slots in the upper layer. The two parts are coupled by an array of 8×8 coupling slots (Fig. 1).

The antenna has been designed and optimized at *f*=350 GHz. A uniform aperture distribution has been chosen for its radiating part. In the simulation we consider the conductivity of the metal layers equal to σ=41×10^{6}S/m.

3. Results

An antenna prototype has been fabricated with silicon process. Five thin metallic laminated plates of 200 μm thickness are used. These plates are silicon wafers where electroless and electrodeposited films were formed on each silicon wafer. They are etched by DRIE, plated by gold on their surfaces and bonded with diffusion bonding process under high temperature (300°C) and high pressure (9KN).

The size of the antenna prototype is 13.7mm × 13.7mm ($16\lambda_0 \times 16\lambda_0$, λ_0 is the free-space wavelength) with a total thickness of 1mm. A vertical transition (WR-3) has been used during the measurement between the antenna feeding aperture in M1 (Fig. 1) and the WR-3 standard rectangular waveguide.

The simulated and the measured reflection coefficients at the input of the antenna are compared in Fig. 2. In the simulation the reflection coefficient is equal to -17.5 dB at the design frequency, f=350 GHz and spans from 338.9 GHz to 359.6 GHz (5.9%) for VSWR<1.5 (S_{11}<-14dB). In the measurement, the refection coefficient is equal to -13.7dB at the design frequency and some ripples are observed within the frequency band of interest. The ripples could come from low isolation in the used directional coupler during the measurement.

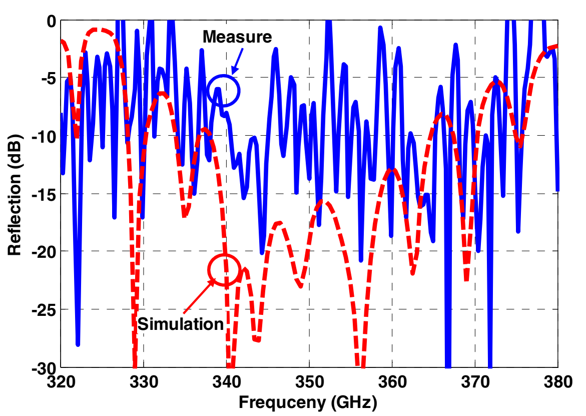

Fig. 2. Input Reflection coefficient. Dashed line: simulation. Solid line: measurement.

The directivity, gain and realized gain in simulation and measurement at the antenna broadside direction versus frequency are shown in Fig. 3. In the measurement, the gain of the antenna prototype is measured by the gain-comparison method with a standard gain horn using electronic system. During the measurement the distance between the two antennas (Tx and Rx) is equal to 61 cm.

At the design frequency, f=350 GHz, the simulated directivity is equal to 32.7 dB. The gain is equal to 31.8dBi in simulation and is around 27dBi in measurement. The gain characteristic versus frequency is flat in simulation and is confirmed by the measurement. The 3dB-down gain bandwidth is 50.8 GHz in simulation and is 44.6 GHz in measurement. To our best knowledge this is the first demonstration of planar antenna with broadband characteristic in gain in the 350 GHz band. More measured results of the realized prototype will be provided during the conference.

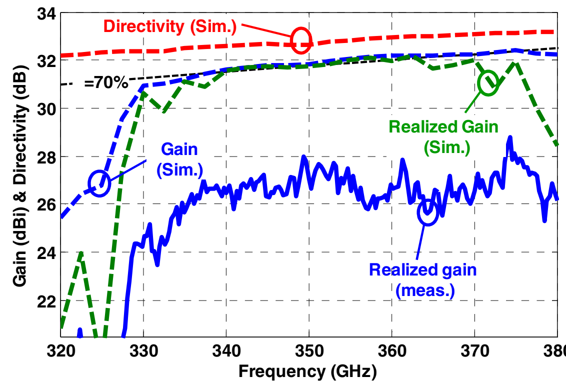

Fig. 3. Simulated gain, realized gain and directivity. Dashed line: simulation. Solid line: measurement.

4. Conclusion

A corporate feed slotted waveguide array antenna in the 350 GHz band has been designed and fabricated. To cope with the severe fabrication tolerances in the submillimeter wave band a new fabrication process with the silicon technology where the fabrication tolerances is about ±5μm has been used. An antenna prototype has been fabricated and measured. Broadband characteristic in term of antenna gain is shown in simulation and demonstrated by measurement. To our best knowledge this is the first demonstration by measurement of a antenna with broadband characteristic in the 350 GHz band.

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