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Micro-Lens Antenna Integrated in a Silicon Micromachined Receiver at 1.9 THz

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***Abstract*—This article presents the latest developments of our work related to a micro-lens antenna integrated in a heterodyne receiver using silicon micromachining technology at Terahertz frequencies. The antenna is composed of a waveguide feed which uses a leaky wave cavity to enhance the directivity and illuminate a shallow lens efficiently. The receiver is a dualpolarized balanced heterodyne detector using hot-electron bolometers (HEB) as mixers. The front-end receiver, including the antenna, can be fabricated using silicon micromachining processes and has seamless integration, which reduces the overall size and losses.**

***Index Terms*— micro-Lens antenna, leaky waveguide, Terahertz, micromachining, DRIE.**

I. INTRODUCTION

Terahertz is a frequency band of scientific importance for the astrophysics community as it contains key information regarding star creation and evolution. The need of high-resolution, multi-pixel, heterodyne spectroscopic instruments is the key for the understanding and mapping of the interstellar medium. These instruments need to be highly sensitive, but at the same time are constrained by the mass and volume limitations of the overall system, as well as by the fabrication restrictions at terahertz frequencies [1].

Deep reactive ion etching (DRIE) based silicon micromachining technology is the most viable option for the fabrication of next generation of terahertz multi-pixel space instrumentation [2]. It provides high precision fabrication capabilities and high level of integration within the receiver [3]. Moreover, it enables the fabrication of hundreds or thousands of pixels from a single wafer, which is a perfect candidate to build future multi-pixel arrays [4].

One of the challenges of the development of multi-pixel heterodyne receivers is the antenna array. For single-pixel instruments, horns are widely used because of their good performance and bandwidth [5]. However, for multi-pixel instruments, these antennas struggle in terms of fabrication – higher frequency requires higher fabrication tolerances – and integration with the rest of the detector because of their volume, mass, and the difficult integration of silicon and metal at cryogenic temperatures [6]. Thus, having an antenna that can be fabricated in silicon micromachining techniques is essential for these receivers.

Multimode corrugated feed horns that are fabricated using silicon micromachining processes at submillimeter-wave frequencies are limited by the fabrication tolerances [7], larger the directivity, and large number of wafers for longer horns. In [8] a new concept of antenna compatible with silicon micromachining techniques was presented, demonstrating performances comparable with horns, while being compatible with silicon micromachining processes fabrication. In this contribution we present the development of a coherent, dual-polarized balanced receiver at 1.9 THz using a micro-lens antenna, all integrated in silicon micromachining technology. This single pixel demonstrator of our technology can be easily extrapolated to a multi-pixel array in the 1-5 THz frequency range because of the fabrication approach and circuit architecture.

II. SILICON MICROMACHINED FRONT-END

The proposed receiver at 1.9 THz is a coherent, dual-polarized balanced system using HEB mixers. The schematics of the design is shown in Fig. 1.

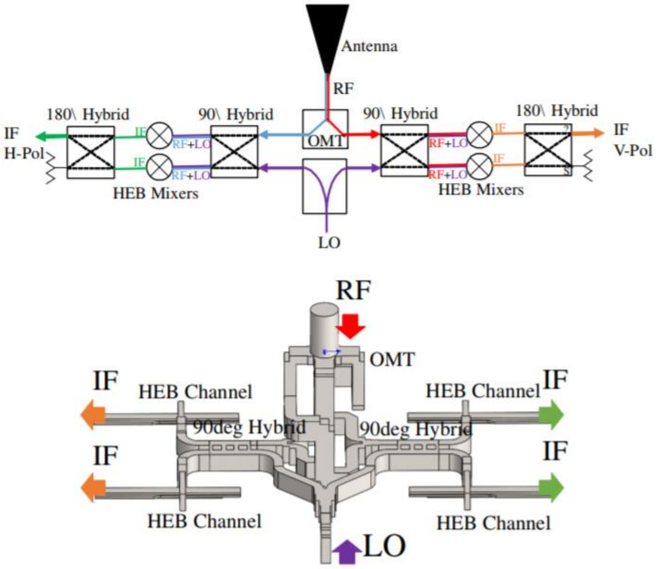

Fig. 1. (top) Block diagram and (bottom) actual waveguide design of the dual-polarized, balanced receiver front-end at 1.9 THz fabricated with silicon micro-machining technology.

In this architecture, the terahertz radiation is coupled to a dual polarized antenna and by using an Ortho Mode Transducer (OMT) the two polarizations of the RF signal are separated [9]. Each polarization goes into a 90-degree hybrid that divides equally the RF and LO between the two other ports with 90-degrees phase difference. The combined RF and LO signal feeds two sets of HEB mixers [10] in a balanced configuration. The IF outputs are then combined in a 180- degree hybrid obtaining the corresponding polarization signal.

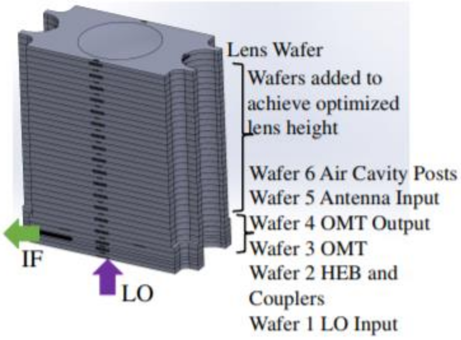

Fig. 2. Schematics of the silicon micro-machined wafer distribution of the front-end receiver.

The actual circuit design and the wafer distribution of the overall assembly including the lens are shown in Fig. 2. All these components are fabricated and assembled using 300μm400μm thick low resistivity silicon wafers and gold plated (except the silicon lens, which uses high resistivity silicon). The wafers are double-side polished in order to provide good wafer-to-wafer contact and silicon pins integrated in the wafers are used for alignment [11]. The LO is generated by a sequence of power amplifiers and multipliers and it is coupled to the circuit by a vertical waveguide. The IF output comes out on the side of the wafer – wafer number 4 in Fig. 2 – and rerouted to the end of the wafer stack where it will be amplified and filtered.

The key advantage of having this vertical integration architecture is that we can easily transition to a two-dimensionally arrayed multi-pixel system.

III. MICRO-LENS ANTENNA

In radio astronomy applications, instruments with high f/D aspect ratio, where f is the focal distance and D is the diameter of the reflector, are required in order to have high resolution images. For this receiver, an f/D ratio of 19.5 has been chosen, which corresponds to the f-number of the Stratospheric Observatory for Infrared Astronomy (SOFIA) instrument. The SOFIA airplane framework carries a telescope with an f-number 19.5 and an effective diameter of 2.5 m to altitudes as high as 14 km. The FPA of SOFIA will host hundreds of THz antennas (pixel elements) to achieve spatial resolutions higher than the state of the art instruments. For this large f-number and considering a double-sampling condition, the optimum aperture diameter corresponds to 6.5mm (40.5λ) at 1.9THz.

The antenna geometry consists of a leaky waveguide feed that provides a very directive feed that illuminates only the upper part of an extended hemispherical lens [8]. An iris will provide the match of the antenna impedance consisting on a 1.5um thick membrane containing two double-slots. Each slot will couple the linearly polarized field into the waveguide. As shown in Fig. 3 a good matching below -15 dB is obtained in the whole frequency band of interest.

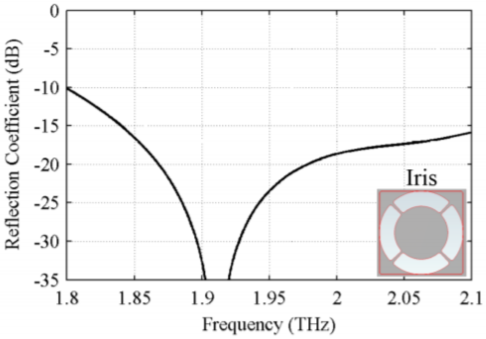

Fig. 3. Schematics of the silicon micro-machined wafer distribution of the front-end receiver.

A micro-lens antenna of an aperture of 6.5mm has been designed achieving a spillover of less than 0.5dB, a Gaussicity above 90% using the design guidelines presented in [12]. Because of the high directive feed, a large lens height is required. In our case for a diameter of 6.5mm, a height of around 15mm in required, which will be achieved by stacking high resistivity silicon wafers between the feed and the lens, as shown in Fig. 2. The resulting illuminated shallow lens and the leaky wave waveguide feed are suited to be fabricated using silicon microfabrication processes using one wafer for the leaky waveguide feed and one wafer for the lens [13]. Therefore, an array of such lens antennas could be fabricated in parallel by just stacking three stacks of silicon wafers as shown in Fig. 2.

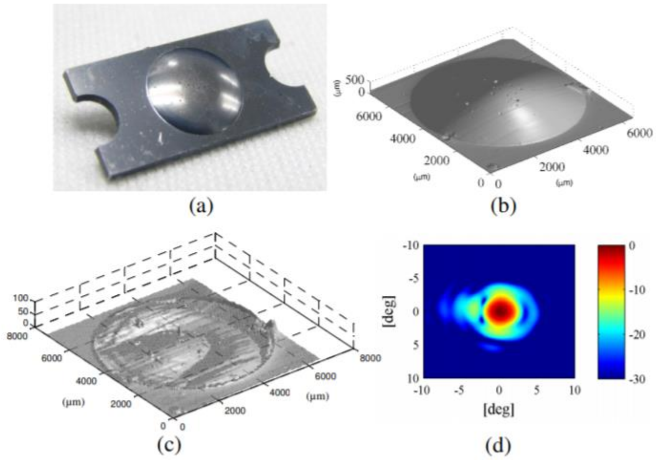

Fig. 4. (a) Photograph of the silicon lens micromachined. (b) 3D Surface generated from the fabricated lens analysis. (c) Error surface of the fabricated lens profile. (d) Simulated 2D radiation pattern obtained from the fabricated lens profile.

The lens profile fabricated using silicon micromachining processes is shown in Fig.4 (a). The surface of the fabricated lens has been characterized using a profilometer (as shown in Fig.4 (b)) in order to study the accuracy of the fabricated shape. The error of the fabricated profile compared to the Fig. 4 desired lens surface is presented in Fig.4 (c). By computing this error we can evaluate the impact that these aberrations have in the radiation pattern of the antenna. From the resulting 2-D radiation pattern of Fig.4 (d), obtained from the fabricated lens profile, we can observe a very good focused pattern, with higher secondary lobes but within tolerable margins. Note that because the highest error is at the edges of the fabricated lens, we have reduced the illumination area in the aperture in order to improve its performance.

IV. CONCLUSIONS

This paper presents the development of a coherent, dual-polarized balanced receiver at 1.9 THz using a micro-lens antenna, all integrated in silicon micro-machined waveguide packaging. Since silicon micromachining allows vertical integration of waveguide structures, we are able to reduce losses of the overall receiver by integrating all the waveguide components and thus reducing its size. This micro-lens antenna employed is fabricated using silicon micromachining process and allows seamless integration with the rest of the receiver.

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