Unilateral finline transition at THz frequencies

Boon Kok Tan and Ghassan Yassin

***Abstract*—We present a new type of waveguide to microstrip transition designs for a 700 GHz SIS mixer. The transition comprised a unilateral finline taper and the RF power from the finline slot is coupled through coplanar waveguide to microstrip using two radial stubs. This transition is significantly easier to design and fabricate than the conventional antipodal finline taper since the fins do not overlap at any stage. A key feature of this design is that it can be deposited on Silicon-on-Insulator resulting in a finline mixer chip on approximately 15 μm silicon substrate. This allows the mixer chip to be held in the E-plane of the waveguide without a supporting groove in the waveguide wall, avoiding the excitation of higher order modes. The chip is simply supported by gold leads deposited on the substrate. It should be emphasized that the employment of such substrate will also decrease the loss and allow finline mixers design to be extended to the THz region.**

***Index Terms*—finline transition, submillimeter wave mixers, slotline transition, coplanar waveguide transition, silicon-on-insulator technology**

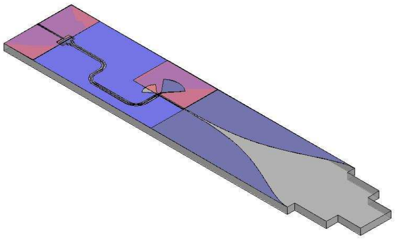

Fig. 1. Full finline chip design on a 15 μm silicon-on-insulator substrate.

I. INTRODUCTION

IN previous publications we have reported the successful operation of SIS finline mixers in the frequency range 220-700 GHz [1]–[3]. These mixers have proven advantageous in providing broadband RF operation. The finline mixer chip is insensitive to mixer block machining tolerances, hence only requires basic block fabrication which becomes important at higher frequencies. The large chip area enables sophisticated planar circuit design to be elegantly integrated into a single detector chip.

The waveguide-to-microstrip taper we have so far employed an antipodal section with overlapping fins separated by a thin insulating layer ($\sim$ 400 nm). Although the fabrication of antipodal SIS mixers chip is certainly feasible, a lot of care is needed during processing in order to avoid narrow spikes that can potentially ac-short the chip, especially at the stage when the fins start to overlap [4]. Moreover, the complicated nature of the finline taper which comprises two dielectric layers and slightly overlaping superconducting fins makes it extremely difficult to compute or even model the electrical behaviour of the structure.

To overcome this difficulty, we have developed a new waveguide-to-planar circuit transition that does not employ an antipodal section [4]. Power is initially coupled from the waveguide using a unilateral finline taper as in the conventional design. The gap width is decreased to about 2 μm in order to decrease the impedance as much as possible while keeping the fabrication feasible with photo-lithography. At this stage, power is coupled to a coplanar waveguide (CPW) with the aid of two radial stubs as shown in figure 4.

A fundamental difficulty in realising the finline mixer design at THz frequencies is because the mixer chip is deposited on a quartz or silicon substrate which has a relatively high dielectric constant. This is because of the mismatch that the loaded waveguide presents to the incoming signal. Moreover, a groove of finite depth and height is needed in order to support the substrate in the E-plane of the waveguide. This can potentially excite higher order modes, hence limits the high frequency end of the mixer bandwidth. So far we were able to overcome this problem by using rectangular noches to match the loaded waveguide to free space and thin the substrate following device fabrication to avoid excitation of higher order modes within the band of operation. For example, at 220 GHz we needed to thin the quartz substrate to 180 μm while at 700 GHz we needed to thin it to less than 70 μm. At higher frequencies, even thinner quartz substrates are required which clearly becomes awkward if not impossible.

The introduction of the Silicon-on-Insulator (SOI) technology which has been reported in recent years overcomes all the difficulties explained above [5]. The ability to fabricate finline chips on extremely thin silicon substrate ($\sim$ 10 μm), will improve the performance of finline mixers, make them easier to design and fabricate, and more importantly extends their operation into the THz region. The very thin substrate presents light loading to the incoming waveguide signal, hence the notch structure may no longer needed and will prevent the excitation of higher order modes within a relatively large bandwidth. The mixer block design will become even simpler and will only consist of two halves of a rectangular waveguide. This is because the light chip will no longer need a deep groove in the waveguide wall but will now be supported by a few microns beam leads deposited on the chip and attached to the waveguide. The advantages of the above proposed idea

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Boon Kok Tan and Ghassan Yassin are with the Department of Physics (Astrophysics), University of Oxford, Denys Wilkinson Building, Keble Road, Oxfordshire, OX1 3RH. (phone: +44 (0)1865 273303; e-mail: tanbk@astro.ox.ac.uk; email:g.yassin1@physics.ox.ac.uk ; email: pxg@astro.ox.ac.uk).

Manuscript received 20 April 2009.

may be summarised as follows:

- The introduction of the new finline avoids the employment of an antipodal finline section which improves the performance of the mixer chip and makes it easier to fabricate and model.
- The employment of SOI allows the fabrication of the chip on a very thin substrate which improves the performance, broadbands the operation and extends it to the THz region.

In this paper, we present the design of a unilateral finline to microstrip transition at 700 GHz, deposited on a 15 μm Si substrate. The transition comprises a unilateral finline section, a slotline to coplanar waveguide section and a coplanar waveguide to microstrip transition, as shown in figure 1.

II. A NEW UNILATERAL FINLINE TO PLANAR CIRCUIT TRANSITION

The SIS finline mixers designed so far employed an antipodal finline section to realise the waveguide to microstrip transition. An important advantage of this design is that it provides an extremely wide band transition from the waveguide impedance to a low microstrip impedance, directly, without intermediate transformers. For example, assuming that the thickness of the isolating layer (SiO) that separates the fins is 400 nm and a microstrip width of 3 μm (which is easy to achieve using standard lithograpy), we obtain a characteristic impedance of 20 Ω, which is ideal for SIS junctions. As explained above however, the employment of an antipodal section presents difficulties in both fabrication and design, hence an alternative design is presented, which provides direct coupling of power from the unilateral finline to a planar circuit. The unilateral finline transition retains the advantages of the finline taper, outlined in the introduction, and yet is much easier to design and fabricate. The resulting transmission line is shorter and hence reduces the insertion loss and allows fabricating a larger number of devices on the same wafer.

Figure 2 shows an example of a unilateral finline taper, deposited on a 15 μm silicon-on-insulator substrate or on 60 μm of a quarts substrate. Power is coupled from the waveguide to the finline taper, which is tapered to the desired gap width gradually using a profile that gives the shortest possible taper [4]. A two-step notch is used on the substrate to match the impedance of the air-filled rectangular waveguide to the loaded waveguide, with broad band performance. Figure 3 shows the computed scattering paramaters of a unilateral finline taper deposited on both 15 μm silicon substrate and 60 μm quartz substrates, using Ansoft HFSS software package. It can be seen that for both the silicon and the quartz substrates, the return loss is less that 20 dB over 200 GHz which is sufficiently broad for many applications. In fact the bandwidth is mainly limited by the 2-stage notch component rather than the finline taper.

A. *Slotline to coplanar waveguide transition*

Planar circuits, in particular those that employ complex structure are usually fabricated in microstrip. This is because this structure provides a well defined frequency independent TEM fields confined between the strip and the ground plane. Moreover, manipulation of this structure has been thoroughly studied and realised in many applications. Making the transition from unilateral finline to microstrip directly however is not feasible in practice since the impedance of a slotline is much higher than that of a microstrip. For example, the impedance of a slotline of 2 μm gap on 15 μm silicon is about 60 Ω while the impedance of a 3 μm wide microstrip is about 20 Ω. Reducing the lateral dimension of the slot or the mirostrip further is not practical using standard lithography.

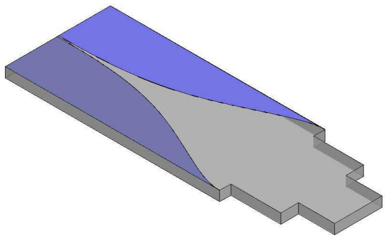

Fig. 2. Example of a unilateral finline taper deposited on a 15 μm silicon-on-insulator substrate.

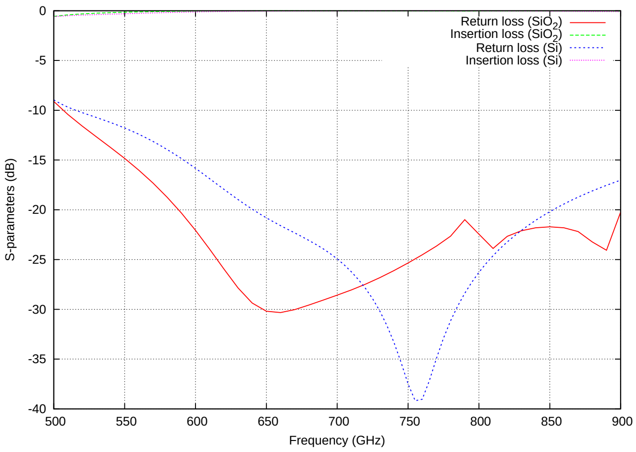

Fig. 3. Scattering parameters of the unilateral finline taper of 15 μm silicon-on-insulator substrate and 60 μm quartz substrate.

The impedance of the coplanar waveguide transition can easily be adjusted to match that of the unilateral finline, with dimensions that can easily be fabricated using photolithography. For example, a 60 Ω CPW can be realised with strip width of 2 μm and gap width of 2.5 μm.

Transition from unilateral finline to CPW is therefore first made. A short section of microstrip bridge is deposited across the slotline on a 425 nm insulator layer, terminated by a quarter wavelength shorted radial stub. The microstrip section is immediately stepped down after the bridge to form the central conductor of the coplanar waveguide. The slotline also is terminated by a radial stub which forms an RF short, as shown in figure 4. We would like to emphasise that since the length of the microstrip bridge is much shorter than a wavelength, the impedance seen by the slot is that of a CPW rather than a microstrip. We had simulate the performance

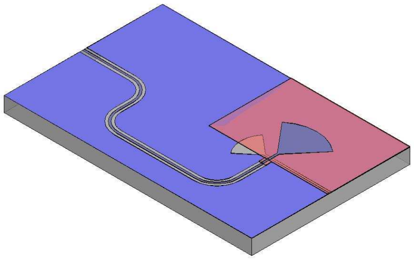

Fig. 4. Slotline to CPW transition via a short section of microstrip bridge. The ground plane, microstrip bridge and the central conductor of CPW is shown in blue, while the insulator layer is shown in pink.

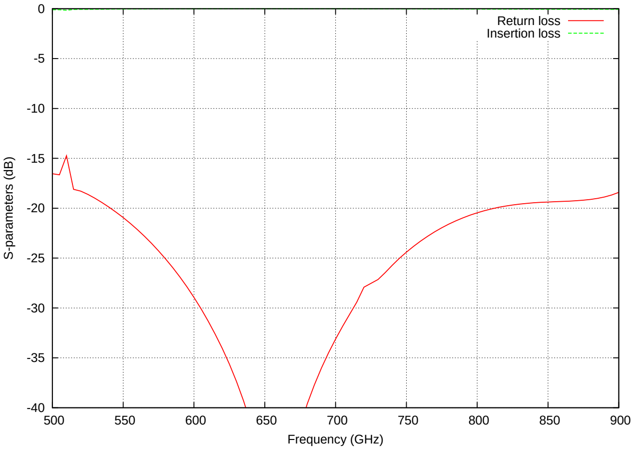

Fig. 5. Coupling efficiency of the transition deposited on a 15 μm silicon substrate.

of the transition using HFSS and the scattering parameters are shown in figure 5. The simulation shows very broad band behaviour at 700 GHz. The return loss is lower than -20 dB across a bandwidth of 350 GHz.

B. Coplanar waveguide to microstrip transition

We have already stated that complex mixer planar circuits such as tuning or sideband separating circuits can easily be realised in microstrip. Consequently, we have designed a three-steps CPW to microstrip transformer which is described in Figure 6. The high impedance of the coplanar waveguide with narrow central conductor is slowly transformed to lower impedance coplanar waveguide by widening the central conductor to match the microstrip line impedance. The central conductor is then stepped up over the insulator layer to form the microstrip line. This stepping-up does not change the field configuration significantly as the thickness of the insulator layer is small compare to the width of the central conductor and the substrate thickness. Figure 7 shows the HFSS simulation of the transition. It can be seen that this simple transition design yields broadband operation although the return loss is typically -20 dB. This performance however can be easily improved by increasing the number of steps or tapering the transition.

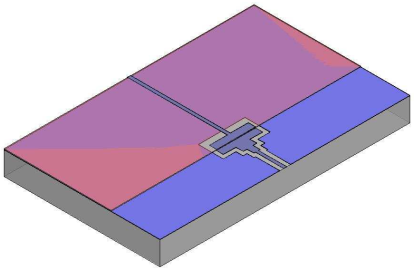

Fig. 6. CPW to microstrip transition via a 3-steps transformer. The ground plane and the microstrip is shown in blue while the insulator layer is shown in pink.

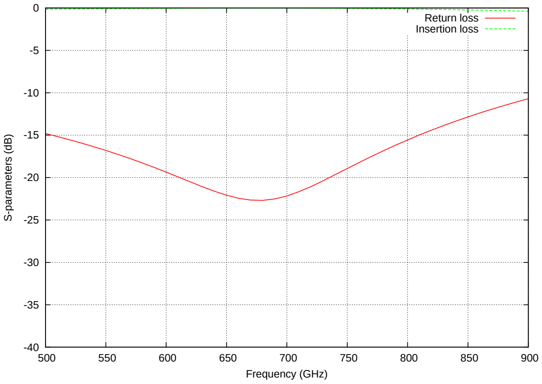

Fig. 7. Coupling efficiency of the CPW to microstrip transition on 15 μm silicon substrate.

III. CONCLUSION

We have presented a new type of waveguide to microstrip transition using unilateral finline deposited on a 15 μm silicon substrate for THz SIS mixers. The transition is deposited on a silicon-on-insulator substrate and hence greatly simplifies the mixer chip and block design and fabrication.

We are currently in the process of designing a back-to-back finline mixer using the above-described technology. The back-to-back design allows the feeding of the signal from one end and the LO from the other, thereby avoiding the employment of beam splitters. This will allow the mixer to be pumped with a much less powerful local oscillator, which can be useful for either the construction of focal plane arrays or the employment of photonic LOs. This, and the available large substrate area will allow elegant integration of sideband separating circuits on the mixer chip.

ACKNOWLEDGMENT

The authors would like to thank Chris North for the support on Finsynth script, and appreciates the useful discussions with Paul Grimes and Jamie Leech.

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