Via-less microstrip to rectangular waveguide transition on InP

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Abstract—**Indium-Phosphide (InP) is one of the most common materials used for realizing active devices working in the millimeter frequency range. The isotropic etching profile of InP substrates limits the realization of passive devices, thus requiring an expensive and lossy hybrid platform. This paper presents a via-less, cost-effective and efficient solution for InP substrate. By using the proposed planar solution, it is demonstrated that rectangular waveguides can be realized on InP by fabricating a bed of nails structure which acts as a reflecting boundary for an impinging millimeter wave. As a proof of concept, a transition from microstrip to rectangular waveguide structure is realized within H-band (220-320 GHz) with a return loss of -18dB over a bandwidth of 30 GHz.**

I. INTRODUCTION

Millimeter wave devices are extensively used for military and security applications. The recent addition of mm-wave spectrum to 5th Generation (5G) mobile communication standard sparked enormous interest into mm-wave systems. The choice of a semi-conductor material for millimeter wave devices is limited to GaAs and InP. Due to diverse properties of InP in electronics as well as optical domain, it is commonly used for realization of active devices such as amplifiers, photo-diodes, lasers etc. The fabrication of guiding structures such as microstrips, co-planar waveguides (CPWs) and rectangular waveguides is quite challenging on InP, due to its isotropic etching profile [1]–[4]. The isotropic response of InP to most etchants results in vias having diameter equal to the depth, which is not desirable for guiding structures. Moreover, the typical thickness of InP substrates is on the order of 125μm, which is not suitable for microstrip structures for the H-band frequencies (220-320 GHz). A CPW structure without a ground plane can be realized on InP, albeit the air-dielectric boundary not only introduces losses but also dispersion (due to higher dielectric constant of InP) limits the high-data rate communication. Grounded-CPW (GCPW) is often realized using either inefficient thinning and etching of through-via holes (wet or plasma etching [5], [6]) or by using a lossy hybrid platform. Also rectangular waveguides are realized using substrate integrated waveguide (SIW) structure but as all of these technologies are not tailored for integrated circuits, provision of through-via holes remains a bottle-neck for InP substrates. Thus, there is a need for a via-less guiding structure which can support rectangular waveguide as well as microstrip modes while keeping the performance comparable to or better than through-via structures.

Inspired from the bed of nails structure [7], [8] used for microwave applications, we propose an alternative via-less inverted bed of nails architecture such that rectangular waveguides can be realized without the need of through-via holes. By properly dimensioning the period and size of the pins/nails, it is possible to create perfect electric and perfect magnetic boundary conditions. Using these boundary conditions, it is possible to create a rectangular waveguide-like structure, where the bed of nails or pins do not need to contact the top and the bottom metal layer. To demonstrate the suitability of this technology, a microstrip to rectangular waveguide transition has been designed for a 30 GHz-wide bandwidth of operation (240-270 GHz). The structure is optimized for commercial fabrication processes on InP substrate.

II. PROPOSED STRUCTURE

The choice of bed of nails architecture for InP substrates is supported by the fact that two metal layers (top and bottom) can confine the E-field by making use of non-contacting rows of metal pins as side walls (Fig.1(a)). The gap between pin and bottom plate should be less than the quarter wavelength [9]–[11]. Thus for a reduced height rectangular waveguide single mode operation, the depth d of the pins can be restricted to 10s of micrometers. In order to prove the feasibility of the proposed via-less technology, a transition from microstrip to reduced height rectangular waveguide is designed. As mentioned earlier that typical thickness (125 μm) of InP substrate cannot support a microstrip structure as the thickness is much larger than the 10 % of wavelength (λ = 0.25 mm - 0.3 mm in H-band). For this reason, the thickness h of InP substrate should be reduced to 50 μm using thinning as the last fabrication step. Using the rectangular waveguide alike structure of Fig. 1(a) also known as gap-waveguide, the bed of nails is optimized such that it will support only single mode (TE_{10}) propagation. The bed of nails is implemented using square shaped pins with g = 7 μm (Fig.1(a)). The depth d of each pin is optimized such that the aspect ratio (AR=d/g) is

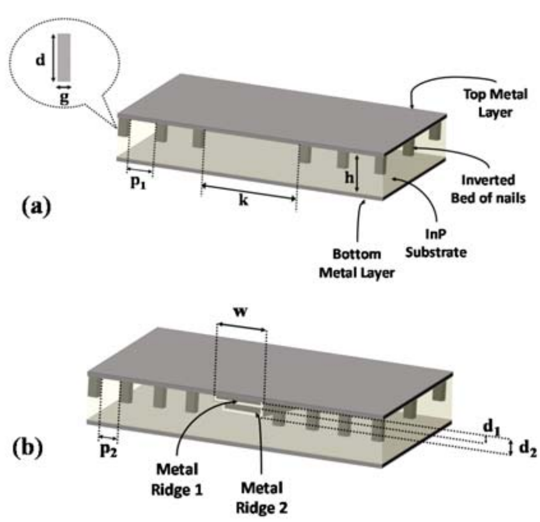

Fig.1. (a) Bed of nails architecture for Gap-waveguide.(b) Ridge based transition in bed of nails.

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less than or equal to 3. It is worth noting that a smaller aspect ratio simplifies the fabrication process by minimizing the etching and metal deposition time. For rectangular waveguide alike propagation, three rows of pins are used to construct side-walls of a rectangular waveguide. The wider dimension k of the rectangular waveguide is equal to a conventional dielectric filled WR-3 waveguide. The period (p_1 = 40 µm) is constant along transversal and longitudinal directions.

After optimizing the bed of nails structure, a transition from microstrip to the gap-waveguides is constructed. From a microstrip architecture (with b = 45 µm), a transition is created using two metal ridges with depth d_1 = 15 µm and d_2 = 35 µm respectively as shown in Fig.1(b). The width w of each ridge is restricted to 15 µm. The pins are of the same dimension as used for aforementioned gap-waveguide structure. By optimizing the periodicity of pins (p_2 = 15 µm), a transition from microstrip to rectangular waveguide is designed. The length of transition section is 100 µm where each metal ridge is 50 µm long.

III. Results and Conclusions

After optimizing the ridge and gap-waveguide structures, the complete structure of Fig.2(a), where input is microstrip and output is gap-waveguides, is simulated. The obtained S-parameters are presented in Figure 2(b). It can be observed that such a transition can provide a return loss of -18 dB over a bandwidth of 30 GHz (240-270 GHz) with insertion loss of -0.15 dB. The size and shape of the pins remains constant across the structure. The periodicity of pins is only varied along the structure for designing transition and gap-waveguide. The metal ridges and pins do not need to be completely filled with metal, rather as long as the cavity walls (created using etching) are metallized, the proposed inverted bed of nails structure can provide required guiding properties.

The advantages of proposed guiding structure are two-folds. On one hand, as the metal pins do not need to contact bottom plate, it eases the etching and metal deposition process. On the other hand, as the bed of nails is deposited using the top metal layer, the InP substrate can be processed prior to thinning. Once the BEOL (back-end of line) process is completed, the substrate thinning can be performed. This provides further ease in handling of InP substrates. The bottom metal layer can be deposited as the last metal deposition step. Also, it can be avoided by placing the InP substrate in a metallic container which is conventionally done for mitigating EMI (electromagnetic interference).

The proposed structure can be used for guiding mm-wave signal from amplifiers or photodiodes to passive components. Various passive components such as antennas, filters, power combiners and cavities can be designed in bed of nails architecture. Therefore, the proposed guiding structure provides an efficient and cost-effective technology which can be implemented on InP substrates using fewer fabrication steps.

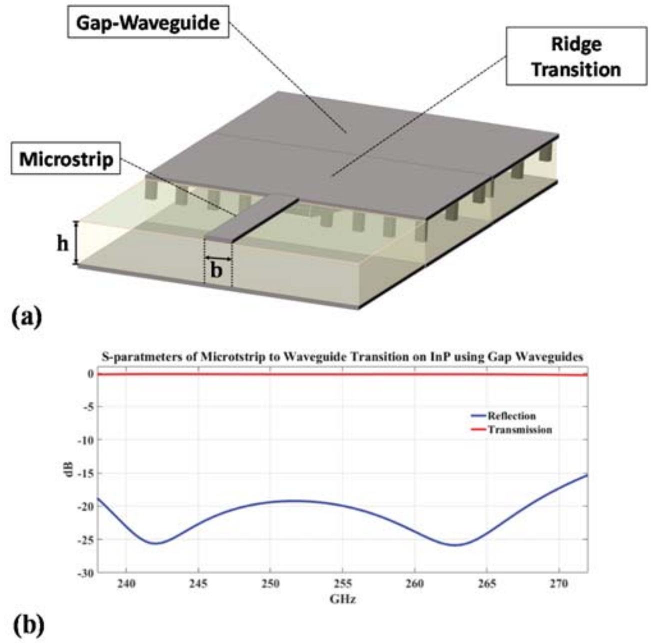

Fig.2. (a)Proposed microstrip to rectangular waveguide transition.(b)Reflection and Transmission of Transition

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