Modelling of Folded Waveguide RF Structure

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Abstract
In recent past, there has been intense interest for the development of devices around 100GHz using technologies of Solid State Devices as well as of Vacuum Tubes. In the present we have synthesized serpentine folded waveguide structure based on an analytical approach. Beam parameters like 10KV beam voltage, 50mA beam current and 200 micron beam diameter have been used for this synthesis. Synthesized input parameters have been used of model RF structure in CTS Microwave Studio to optimize for the required operating frequency.

Keywords: THz, Folded Waveguide RF Structure, Vacuum Microelectronics Devices.

I. Introduction
Terahertz sources have enormous potential for applications in high data rate communication, remote sensing, medical and strategic tomography, space research medicines, advanced electronic materials spectroscopy, etc [1]. We have opted to design and develop 100 GHz folded waveguide RF structure travelling wave tube employing vacuum microelectronics technology. Due to the ballistic motion of the electrons devices in vacuum have the advantages of low ohmic losses, high electrical breakdown strength, high efficiency and power densities at these frequencies range. Operating principles of these vacuum microelectronic devices are the same as that of microwave tubes while for fabrication requires both vacuum microelectronics/MEMS technology as well of vacuum tubes. Folded waveguide TWT RF structure has advantages for its robust structure and high power capability along with the advantage of simpler coupling and reasonable wide bandwidth [2].

II. Design Approach
Design and synthesis approach by Han [3] for 34 GHZ FWTWT has been used for 100 GHZ RF structure design. Five input parameters have been used viz. center frequency, operating voltage, beam current, beam radius and space harmonic number. The schematic diagram of the folded waveguide circuit is shown in Figure 1. The periodicity of the folded waveguide itself slows down the velocity of an electromagnetic wave and generates space harmonics along the beam propagation direction.

At center frequency, ω₀, the propagation constant of the spatial harmonic, should match that of the slow space-charge wave in the electron beam, β₀;

\[ \beta_c = \beta_p = \frac{\omega + \omega_p}{\nu_b} = \beta_s \left( 1 + \frac{\omega_p}{\omega_b} \right) = \beta_m. \]

Where, ω₀p is the plasma angular frequency, and vb is the electron beam velocity. At the same instance, the group velocity should be synchronized to that of the slow space-charge wave, vss;

\[ \frac{d\omega}{dk_m} \bigg|_{k_m=\beta_0} = \nu_{ss} \left( = \frac{\omega_0b}{\beta_c} \right). \]

The geometric parameters of a folded waveguide operation as:

\[ \frac{h}{p} = -1 + \frac{\sqrt{1-x^2}}{(\nu_{ss}/c)} \quad \text{and} \quad p = \frac{(2n+1)\pi}{\beta_0 x^2}. \]

Universal equation on x is:

\[ x + x^4/2(1-x^2) = 1 \]

R, as shown in figure 1 is approximated as p/2. Waveguide dimensions are obtained using cutoff frequency in rectangular waveguide where a=2b. The synthesized dimensions so obtained as shown in Table 1, are then optimized in microwave studio for required dispersion.
III. Fabrication Techniques

Advances in micro fabrication technology have enabled the fabrication of electron devices producing radio frequency power in millimetre and sub-millimetre range [3]. There are various techniques which have been attempted for fabrication of RF structures for 100GHZ and above frequencies. Mainly such techniques are LIGA (Lithographe, Galvonoformung, und Abfornung), DRIE, EDM

A. LIGA

In LIGA PROCESS, Poly-methylmethacrylate (PMMA) is deposited on a metal substrate which is exposed with suitable mask either by ultra violet, if is UV lithography or by X-rays from synchrotron source for x-ray lithography. Devices in context are fabricated by X-ray lithography method by exposing it by X-rays of energy from 3000-10,000J/cm3 for several hours. High aspect ratio of more than 50 and surface roughness less than 30nm could be achieved. X-ray lithography has become new generation VMD fabrication technique mainly because of improvement in technologies such as in Stepper Stage, Alignment system, Mask making and Illumination system.

B. DRIE

Deep reactive ion etching (DRIE) is a process where high-aspect ratio structures are etched into silicon. These structures can be used to generate molds or serve as a mold itself for generating metallic structures. Chemicals based on Fluorine are used for etching for its high etches rates, e.g. 10um/min. Aspect ratio of 100:1 could be achieved. Books et. al. [3] have used this technique to develop sub-millimetre folded waveguide travelling wave tube.

C. Electrical Discharge Machining

Electrical discharge machining (EDM) is a precision metal removal process from a conductive substrate using thermal energy from a fine accurately controlled electrical discharge. EDM technique has been used to develop 600-700 GHZ backward wave oscillator (Smith-Purcell based tunable THZ source). EDM technique has advantage over lithographic technique that it can generate 3-D structures. Lithographic technique is generally used to fabricate 2-D structures.

D. Electrochemical Milling

Electrochemical milling is similar to plunge EDM, except that ultra short voltage pulses are applied in the presence of a static or low frequency potential in an electrolytic bath 25um diameter hole with an accuracy of 100-200nm has been reported in the literature [3]. They have produced 5um hole up to 1mm deep using a machine capable of producing 1000-A 500-ps pulses.

E. Laser Micromachining

Various laser sources, such as, copper vapour laser, Nd-YAG etc., have been used to fabricated VMD with different combination of wave length, pulse duration, energy and pulse frequency. The technique is suitable to micromachine metals, ceramics, silicon and polymers. Metals are machined by nano-pico sec pulse laser. Dielectrics by Femto second pulse laser and polymers by UV laser (Xecl, KrF, and ArF). Appropriate parameters and processing strategies nano-sec laser can be used to micro machine metals, ceramics and polymers.

IV. Results and Discussions

Using the basic equations of section I, the physical parameters of folded waveguide structure has been obtained, as depicted in Table I

<table>
<thead>
<tr>
<th>Table I: Synthesized Dimensions</th>
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<tbody>
<tr>
<td>For 100GHZ Folded Waveguide RF Structure</td>
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<tr>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>Width(a)</td>
</tr>
<tr>
<td>Height(b)</td>
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<tr>
<td>Height(h)</td>
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<tr>
<td>Period(p)</td>
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<td>Radius(r)</td>
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Synthesized physical dimensions have been modeled in CST Microwave Studio, as shown in Figure 2 with couplers. Structural dimensions have been so optimized that we get nearly 100 GHz in the dispersion characteristics at 1.3π propagation constant.

Dispersion, transmission characteristics and interaction impedance have also been studied for this structure with the variation in physical dimension of a, b, with and without beam hole etc. Figure 3 shows the dispersion characteristics using synthesized dimension of rectangular waveguide.

Interaction impedance of folded waveguide structure modelled has been obtained by estimating the maximum electrical field intensity of the first harmonic along the central axis of the RF structure (Figure 5). Less than 200 ohms of interaction impedance has been obtained at less than 102 GHz.

Using basics of the transmission line theory, input-output couplers have been designed and transmission studies in folded waveguide structure
with I/O couplers have been carried out in CST MWS (Figure 2 and Figure 6)

Fig.6. Transmission studies in folded waveguide structure with input-output couplers

V. Conclusion

Folded waveguide RF structure at 100 GHZ for Terahertz Source development has been modeled in CST Microwave Studio and optimized for required frequency of operation and transmission. Studies of various fabrication techniques reveal that for these dimensions of RF structure could be fabricated by X-ray lithography, micro EDM or laser cutting.

References