Design of RF Structure for a Terahertz Source

AK Sharma[1], RK Sharma[1], Gargi Dixit[2], Monika Lathar[3] and V Srivastava[1]
[1]Microwave Tubes Area, Central Electronics Engineering Research Institute, Pilani-33031(Raj.)
[2]Banasthali Vidya Pith University, Rajasthan and [3]Vaish college, MDU, Rohtak.
E-mail: aks_370@yahoo.co.in

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

Index Terms:-**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 traveling 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 it 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, ω_0, the propagation constant of the spatial harmonic, should match that of the slow space charge wave in the electron beam, β_c;

$$\beta_c = \frac{\varpi + \varpi_p}{v_b} = \beta_c\left(1 + \frac{\varpi_p}{\varpi}\right) \equiv k_m \qquad (1)$$

Where, ω_p is the plasma angular frequency, and v_b is the electron beam velocity. At the same instance, the phase velocity should be synchronized to that of the slow space-charge wave, v_{ss};

$$\left(\frac{\varpi}{k_m}\right) = v_{ss} = \frac{\varpi_0}{\beta_c} \qquad (2)$$

The geometric parameters of a folded waveguide operation are obtained as [3]:

$$\frac{h}{p} = -1 + \frac{\sqrt{1-x^2}}{v_{ss}/c} \qquad (3)$$

Universal equation on x is;

$$x + \frac{x^4}{2(1-x^2)} = 1 \qquad (4)$$

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

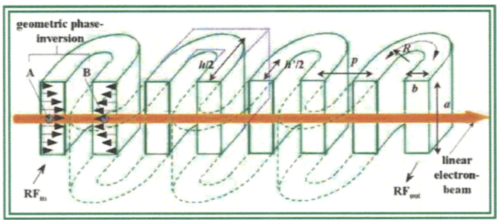

Figure 1 Folded waveguide structure [3]

III. Fabrication Techniques

Advances in micro fabrication technology have enabled the fabrication of vacuum electron devices producing radio frequency power in millimeter and sub-millimeter range [3]. There are various techniques which have been attempted for the fabrication of RF structures for 100 GHz and above frequencies. Mainly such techniques are LIGA (Lithographe Galvanoformung und Abformung), DRIE (Deep Reactive Ion Etching), EDM (Electro-discharge Machining), etc

A. *LIGA*

In LIGA process, poly-methylmethaneacrylate (PMMA) is deposited on a metal substrate which is exposed with suitable mask either by ultra violet, if it is

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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 – 10,000 J/cm^3.for several hours. High aspect ratio of more than 50 and surface roughness less than 30 nm 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 aspect ratio structures are etched into silicon. These structures can be used to generate moulds 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. 10μm/min). Aspect ratio of 100:1 could be achieved. Booske et. al.[3] have used this technique to develop sub-millimeter folded waveguide traveling wave tube.

C. *Electrical Discharge Machining*

Electrical discharge machining is a metal removal process from conductive substrate using thermal energy from fine accurately controlled electrical discharge. EDM technique has been used to develop 600-700 GHz BWO [4] (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 method is similar to plunge EDM technique except that ultra short voltage pulses are applied in the presence of a static or low frequency potential in an electrolytic bath[ ] 25 μm diameter hole with an accuracy of 100-200 nm has been reported in the literature [5]. They have produced 5 μm hole up to 1 mm deep using a machine capable of of producing 1000 A 500 ps pulses..

E. *Laser Micromachining*

Various laser sources, such as, copper vapor laser, Nd-YAG etc., have been used to fabricate VMD with different combination of wave length, pulse duration, energy and pulse frequency. The technique is suitable to micro machine metals, ceramics, silicon and polymers. Metals are machined by nano-pico sec pulse laser, Dielectrics by Famto second pulse laser and Polymers by UV laser (XeCl, KrF, 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

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 at1.3π propagation constant.

TABLE I: Synthesized dimensions

For 100 GHz folded waveguide RF structure	Dimensions in microns
Width (a)	1600
Height (b)	274
Height (h)	1396
Period (p)	528
Radius (r)	264

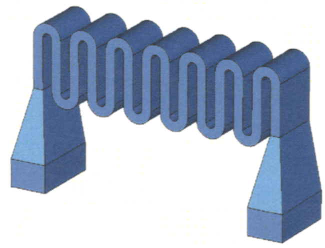

Fig.2. RF Structure with Couplers

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. Figure 3 shows the dispersion characteristics using synthesized dimensions with the variation in longer dimension of rectangular waveguide (a).

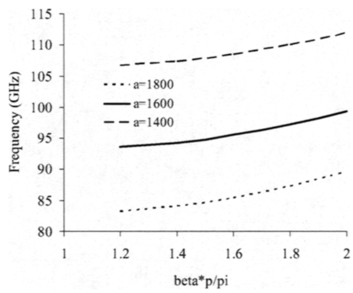

Fig.3. Dispersion Characteristics with different longer rectangular waveguide dimensions.

With and without beam hole the dispersion characteristics have also been studied (Figure 4). Folded waveguide structure with a=1500 micron and the beam hole of 200 micron radius, at 1.3π propagation constant the frequency obtained is around 100 GHz.

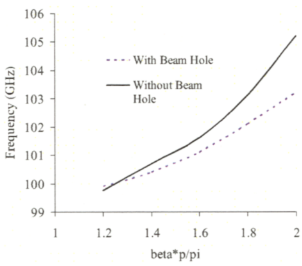

Fig.4. Dispersion characteristics with beam hole and without beam hole.

Interaction impedance of the folded waveguide structure modeled 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 frequency.

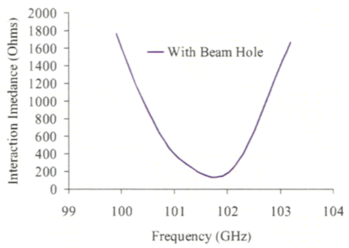

Fig.5. Variation of interaction impedance of the folded waveguide structure with beam hole of 200 micron radius.

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 MS (Figure 2 and Figure 6)

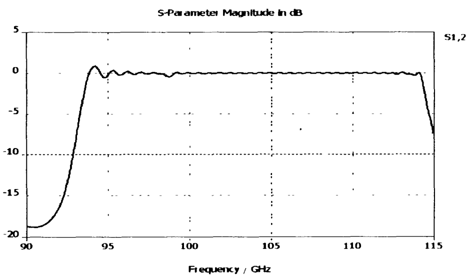

Fig.6. Transmission studies in folded waveguide structure with input-output couplers

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.

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REFERENCES

1. P.H.Siegel, "Terahertz Technology", IEEE Trans. Microwave Thery Tech. vol. 50, pp. 910-928, Mar.2002.
2. S. Bhatttacharjee, "Folded Waveguide Traveling Wave Tube Sources for Terahertz Radiation", IEEE Trans. On Plasma Science, vol.32, no.3, pp1002-1014, June 2004.
3. Seong-Tae Han, Jung-II, and Gun-Sik Park, "Design of a Folded Waveguide Traveling-wave Tube", Microwave and Optical Technology Letters, vol 38, no.2, pp-161-165, July 2003.
4. R. L. Ives, "Micro-fabrication of High –Frequency Vacuum Electron Devices", IEEE Trans. Plasma Sciences, vol.32, no.no.3, pp 1277-1290, 2004.
5. T. Gmelin, H. Kuck, Kock, and R. Schuster, "High aspect ratio ultra precise machining of stainless steel by electro chemical milling with ultra short pulses," in *High aspect Ratio Micro-Machining Technology Workshop,* Monterey, CA, June 2003.