Micromachined TWTs for THz Radiation Sources

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Introduction

The Terahertz (THz) region of the electromagnetic spectrum (~ 300 – 3000 GHz in frequency or ~ 0.1 – 1 mm free space wavelength) has enormous potential for high-data-rate communications, spectroscopy, astronomy, space research, medicine, biology, surveillance, remote sensing, industrial process control, etc. It has been characterized as the most scientifically rich, yet underutilized, region of the electromagnetic spectrum [1]. The most critical roadblock to full exploitation of the THz band is lack of coherent radiation sources that are powerful (0.001 – 1.0 W continuous wave), efficient (≥ 1%), frequency agile (instantaneously tunable over 1% bandwidths or more), reliable, and comparatively inexpensive [1]. To develop vacuum electron device (VED) radiation sources satisfying these requirements, fabrication and packaging approaches must be heavily considered to minimize costs, in addition to the basic interaction physics and circuit design. To minimize size of the prime power supply, beam voltage must be minimized, preferably ≤ 10 kV.

Solid state sources satisfy the low voltage requirement, but are many orders of magnitude below power, efficiency, and bandwidth requirements [1]. On the other hand, typical fast-wave VED sources in this regime (e.g., gyrotrons, FELs) tend to be large, expensive, high voltage and very high power devices unsuitable for most of the applications cited above. VEDs based on grating or inter-digital (ID) circuits have been researched and developed [2]. However, achieving forward-wave amplifier operation with instantaneous fractional bandwidths > 1% is problematic for these devices with low-energy (< 15 kV) electron beams. Moreover, the interaction impedance is quite low unless the beam-circuit spacing is kept particularly narrow, often leading to significant beam interception.

One solution to satisfy the THz source requirements mentioned above is to develop micro-machined VEDs, or "micro-VEDs". Among other benefits, micro-machining technologies provide superior high frequency wall conductivity as a result of superior surface smoothness compared with conventional mechanical or electric discharge machining approaches. Micro-VED technologies are already being applied to the development of millimeter-wave klystrons at Stanford Linear Accelerator Center [3] and submillimeter-wave klystrons at the University of Leeds [1]. We are investigating the use of micro-machining technologies to develop THz regime TWTs, with emphasis on folded-waveguide TWTs.

The folded-waveguide TWT (FW-TWT) has several features that make it attractive for THz-regime micro-VED applications. It is a relatively simple circuit to design and fabricate, it is amenable to precision pattern replication by micro-machining, and it is has been demonstrated capable of forward-wave amplification with appreciable bandwidth [4].

We are conducting experimental and computational studies of micro-VED FW-TWTs to examine their feasibility for applications at frequencies from 200 – 1000 GHz.

Simulation

A preliminary computational examination of a 600 GHz FW-TWT amplifier has been completed using the 3D electromagnetic particle-in-cell (PIC) code MAFIA (Solution of MAxwell's equations by the Finite-Integration-Algorithm) [5, 6]. As done previously for helical circuits in [7], the MAFIA eigenmode solver was used to apply quasi-periodic boundary conditions at the longitudinal ends of a single period (two FW cavities) of the structure permitting the frequency and interaction impedance to be obtained at several values of axial phase shift. The dispersion and impedance are shown in Figure 1 and Figure 2, respectively. The PIC solver of MAFIA was used to simulate 100 cavities (6.6 mm) of the FW circuit with rectangular waveguide input/output coupling (dimensions 0.3 x 0.043 mm), and a 1.8mA, 10.9 kV beam contained by solenoidal focusing. A simulated two-dimensional plot of a full period of the FW circuit with electron beam is shown in Figure 3.

Preliminary simulations for the 100 cavity structure show about 11 dB of gain over a 10% bandwidth. The illustrative parameters were not selected from an optimized set, and further refinements are under investigation.

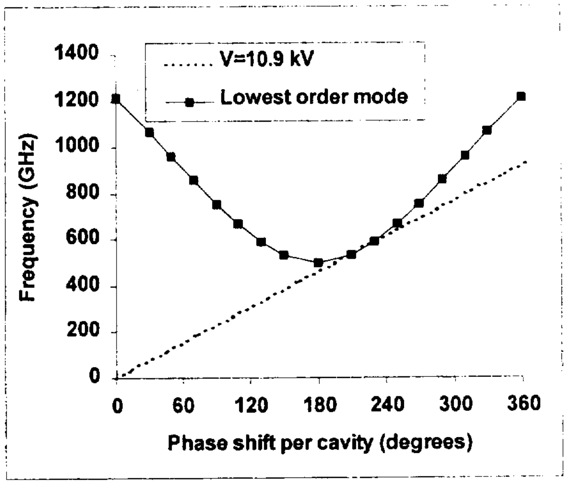

Figure 1 Simulated dispersion for FW circuit with 10.9 kV beam line

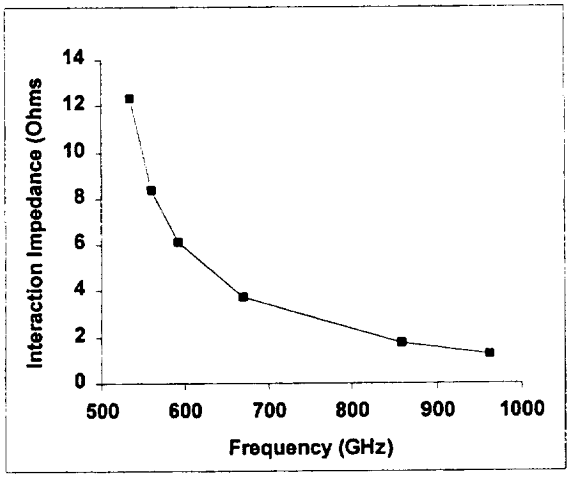

Figure 2 Simulated interaction impedance for FW circuit

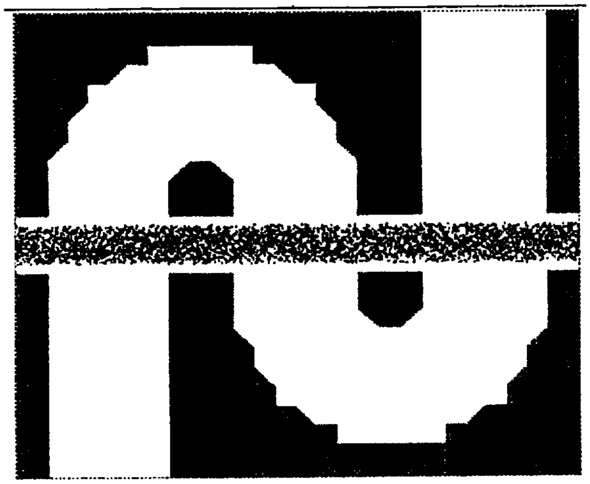

Figure 3 Two-dimensional plot showing simulated electron beam traversing through two cavities of the FW structure

Experiment

In a parallel experimental program we are investigating the performance of short wavelength FW-TWTs, starting with a proof-of-concept device designed for operation near 200 GHz. Beam energy for this scaled, proof-of-concept experiment will be ~30 kV, owing to a readily available field emission source at this energy (final device designs call for beam voltages between 5 and 10 kV). Prototype circuits have been designed and mechanically fabricated using miniature, precise tooling, as illustrated in Figure 4. First experiments investigating the radiation properties of these circuits will be based on an oscillator configuration, and will compare measurements and theoretical predictions for frequency and power. Follow-on experiments will examine amplifier configurations.

Various micro-machining techniques for fabricating the circuits are being investigated. Recommended approaches, along with designs for input-output couplers and the first experimental results with the 200 GHz oscillator circuits will be discussed in this talk.

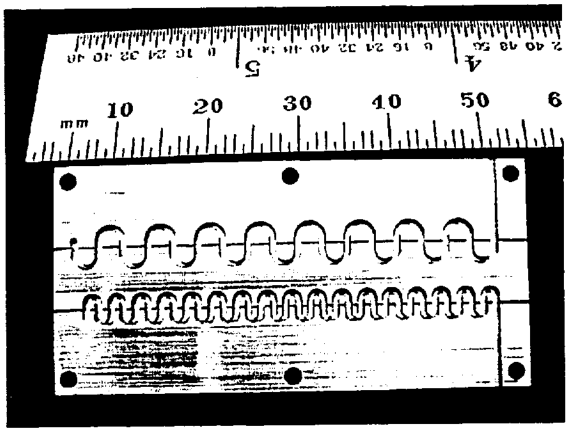

Figure 4 FW prototype circuit

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