1.1: A Compact, High Power, 0.65 THz Source

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Introduction

Since demonstrating the operation of a vacuum electronic (VE) THz source [1], Northrop Grumman Corp. (NGC) has continued to develop our VE-based folded waveguide (FWG) technology as part of DARPA's Terahertz Imaging Focal Plane Array Technology (TIFT) source development program. Significant improvements have been made to the compact THz source, increasing the output power, efficiency, and operational duty cycle. Several sources have been fabricated and operated between 0.605 and 0.675 THz at RF power levels up to 52 mW at duty cycles up to 3%.

THz Source Design Refinement

The THz source shown in Figure 1 consists of a thermionic electron gun, a FWG regenerative oscillator circuit, a depressed collector, and a 10 kG Nd-Fe-B permanent magnet solenoid to confine the electron beam. The cathode is a conventional M-coated 411 cathode with an integral focus electrode. The FWG resonant circuits for these THz sources are fabricated using deep reactive-ion etching (DRIE), and the thermo-mechanical benefits of these FWG structures have been described previously [1]. A single-stage depressed collector is used to recover energy from the spent beam. In order to improve the efficiency and increase the output power, recent design efforts were focussed on four key areas: electron gun electrostatic design, beam transport magnetics, FWG circuit and output waveguide design and the collector design.

MICHELLE 3D [2] was used to analyze the effects of misalignments and transverse magnetic fields on beam focus. Focus and transport of a 4 mA beam through the 60 x 60 μm^2 beam tunnel is a technical challenge as both axial and radial offsets can lead to significant interception of the beam. Because of the small size of the cathode, edge emitted electrons play a large role in the overall beam focus. Edge emitted electrons are more likely to be intercepted (reducing the source efficiency), and therefore efforts to minimize the amount of edge emission were employed. Additionally, the effects of transverse magnetic fields on beam transmission were analyzed. Localized fields of a few 10's of Gauss (<1% of the axial field) can force the beam off axis leading to significant intercept. For an ideally aligned gun with minimal transverse fields present, MICHELLE modelling indicates that 95% of the beam is focussed into the beam tunnel.

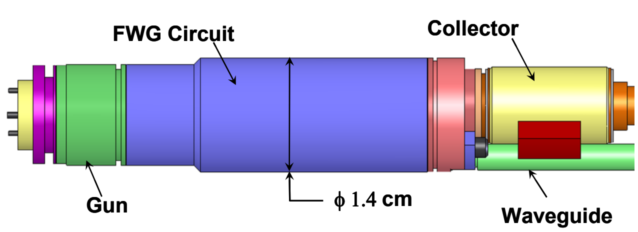

Figure 1. THz source schematic.

Several magnet assemblies were built for the program, and each was carefully characterized by mapping the transverse field component within the magnet bore and its variation along the axis. Precision shims were used to minimize the transverse fields, and then the overall tilt of the magnetic field relative to the geometric axis was determined. Precision fabrication of the electron gun assembly, accurate mechanical alignment of the gun with the beam tunnel in the FWG circuit, and minimization of the transverse fields have lead to a beam transmission of 78% for a 4.8 mA beam at 10 kV in a recent prototype.

Redesign of the RF circuit was completed with NGC's proprietary codes with guidance from CHRISTINE 1D [3]. The feedback in the oscillator circuit and the circuit length were adjusted to maximize the output power of the device. Lastly, the output waveguide of the FWG circuit was designed to be part of the circuit die, and thus was fabricated concurrently with the FWG circuit DRIE and metallization. This modification (previously the output section of the waveguide was made via EDM) resulted in a reduction in the internal losses by ~0.6 dB.

The final design task was to employ MICHELLE 3D to design an asymmetric, single-stage collector. CHRISTINE 3D [3] was used to generate a spent beam distribution for injection into the collector model. An optimized collector efficiency of 92.4% was predicted for a POCO graphite lens with secondary electron emission included. Thermal modelling for 50% duty operation indicates a manageable temperature increase of 40 ^{o}C on the collector shell surface.

Test Setup & Results

After assembly and exhaust, the VE FWG THz source is mounted on the test stand in the bore of the permanent magnet solenoid. Beam focus and transmission are controlled by the alignment of the magnet relative to the

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PARAMETER	Source #3
Power @ window	52 mW
Frequency	0.656 THz
Gain	~15 dB
Cathode voltage	9.9 kV
Pulse length	0.05 – 1.0 ms
Repetition rate	≤30 Hz
Duty cycle, max.	3 %
Axial field	10 kG
Emission current	4.6 mA
Collector current	2.1 mA
Beam transmission	46 %
Interaction efficiency	0.4 %
Source efficiency	0.2 %

Table 1. THz source #3 operation parameters.

source, which is adjusted with two 3-axis translation stages. A cylindrical copper waveguide serves as an overmoded, external output waveguide to transmit RF output power to the THz detector. A 2L/s ion pump maintains the vacuum, and nitrogen gas flows through the magnet bore to stabilize the temperature of the source during testing. Finally, a diode detector and an Erickson Instruments calorimeter are used to measure RF output power, and a harmonic mixer is used to determine the oscillation frequencies.

Table 1 summarizes the operating characteristics for a recent THz source prototype. Source #3 operated at 0.656 THz, 9.9 kV, and 46% beam transmission. Measured power measured at the output window was 52 mW, a greater than threefold improvement in the output power compared to the previous results [1]. While the beam transmission increased to 46%, the source efficiency only improved to 0.2% indicating that the intercepted current must be reduced further to improve efficiency. The frequency is observed to step-tune as the beam voltage is varied from 9.6 kV to > 10 kV. Finally, stable operation of source #3 was achieved with collector depression to 90% of the beam voltage resulting in a collector efficiency of 89%.

The alignment accuracy was improved further with source #4, and the beam transmission has been increased to 78% at 10 kV. RF output has been observed, and quantification measurements are in progress.

Conclusion

NGC has built and tested two additional VE FWG THz prototypes. At 0.656 THz, 52 mW of output power has been demonstrated for duty cycles up to 3%. Source #4, currently on test, has a vastly improved beam transmission of 78% at 10 kV, and full RF characterization is presently being completed. The refinements in the gun, circuit, beam transport magnetics, and collector design have enabled these achievements, and further efforts will lead to the goal of a 1% wall-plug efficiency.

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