Gridded cusp gun for a terahertz gyro-amplifier

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***Abstract*—A terahertz gyrotron traveling wave amplifier (gyro-TWA) centered at 372 GHz is under development for the electron paramagnetic resonance (EPR) imaging application. This paper reports on the investigation of a triode-type cusp electron gun for the 372 GHz gyro-TWA. The simulation results showed that at the beam alpha (the ratio of transverse to axial velocity) centered at 1.07, an optimal alpha spread of ~10% was achieved when it was operated at a beam voltage of 50 kV and a beam current of 0.35 A.**

I. Introduction

The electron paramagnetic resonance (EPR) imaging has important applications in biochemistry, life sciences, and solid-state materials research. The high field EPR requires high-frequency millimeter wave excitation, for example, millimeter wave sources at 372 GHz are required for EPR carried out at 13.3T. One of the important developments of the EPR technology is pulsed excitation, which allows time domain analysis to be carried out for the study of dynamic 'in vivo' biochemistry samples. EPR deals with the unpaired electrons. To achieve a high signal-to-noise ratio in the pulsed excitation, a high excitation power is required. A high power terahertz amplifier is therefore required for the EPR application. A broadband high power gyrotron traveling wave amplifier operating at the center frequency of 372 GHz is under development for this demanding EPR application.

There exists a couple of options to operate the gyro-TWA in pulsed mode. The simplest is to switch on and off the input seed signal. However, in this case, all the electron power will be wasted and finally dissipated as heat and thermal stress on the cooling system. Since the beam tunnel at high frequency becomes much smaller, this approach is not desirable for CW operation or operation over extensive periods of time. The other option is to switch the high voltage at the cathode. This is also difficult as the rise-time will be long and a relatively large noise will be generated. Another approach is to switch on and off the beam current by applying a grid at the front of the cathode, similar to the gridded gun in a conventional traveling wave tube. In this paper, the feasibility of employing a grid structure to a terahertz gyro-amplifier is presented.

II. Design of the Gridded Cusp Gun

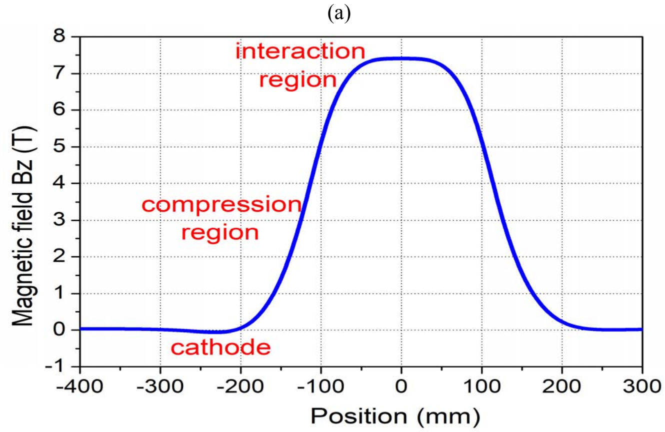
In the gyro-TWA, a helically corrugated waveguide is used as the interaction region, and a cusp electron gun is used to generate a large orbit axis-encircling electron beam. The design of the cusp electron gun for the high-frequency gyro-TWA was based on the previous experience of two guns for two W-band gyro-devices, a gyrotron backward wave oscillator (gyro-BWO) [1] and a gyro-TWA [2-5].

Differing from the gridded structure used for the Pierce gun, the cusp electron gun uses a hollow emitter. The thickness of the emitter is small, making the grid structure difficult to design and manufacture. It is more realistic to use a modulation electrode, which has been used in the magnetic injection guns (MIGs) to provide an extra degree of freedom to improve the beam quality [6]. A triode-type cusp electron gun based on this concept was designed for a W-band gyro-TWA [7].

The parameters of the cusp electron gun were derived from the requirement of the gyro-TWA. The beam voltage is 50 kV, the beam current is 0.35 A, and the magnetic field strength in the interaction region is 7.4 T. The choice of the emitter radius is a tradeoff between the intrinsic velocity spread caused by the emitter thickness and the emitted current. A thinner emitter is preferred to help to reduce the velocity spread, however, it cannot be too small because of the physical constraint of the experiment.

The magnetic field is generated by a superconducting magnet. It contains 6 coils, including the main coil and 2 'shim' coils, and 3 reverse coils. The superconducting magnet and its magnetic profile are shown in Fig. 1.

(a)



(b)

Fig. 1 (a) The superconducting magnet and (b) the magnetic field profile.

Fig. 2 shows the schematic geometry of the triode-type cusp electron gun. The bias voltage of 1 kV was used on the modulation electrode to allow fast switching of the electron beam. The gap distance of the modulation electrode to the emitter was chosen as 0.2 mm. The geometry was fully parameterized and an optimization routine was used to search for the optimal geometry parameter sets, as well as the optimal position of the superconducting magnet.

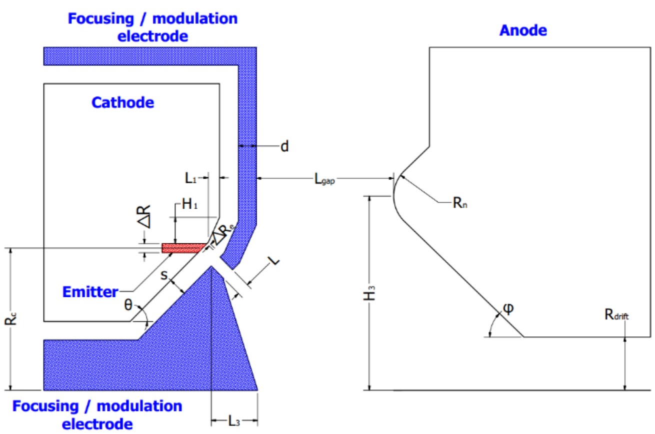
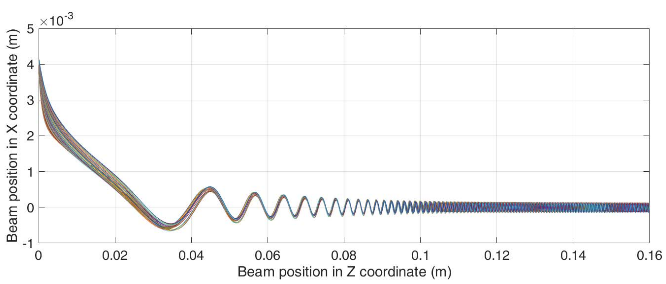


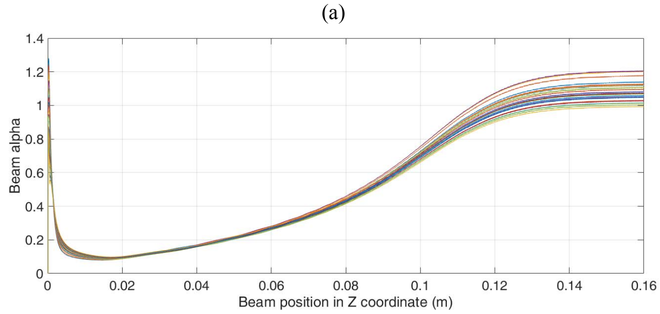
Fig. 2 The geometric model of the triode-type cusp electron gun.

III. SIMULATION RESULTS

Fig. 3 shows the simulated beam trajectory and the beam alpha values of the optimized triode-type cusp electron gun.



(a)



(b)

Fig. 3 (a) The simulated beam trajectory and (b) beam alpha as a function of the axial position.

The beam alpha at the entrance of the beam wave interaction region has also been studied to obtain the alpha spread. The result is shown in Fig. 4. The maximum and minimum alpha values in the simulation are 1.26 and 0.92, respectively. The alpha spread taking into account its full width at half maximum (FWHM) is 10%.

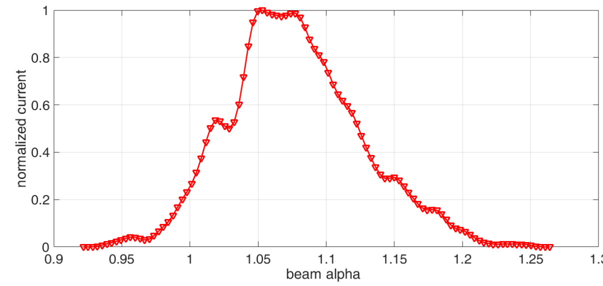


Fig. 4 The alpha spread of the designed electron gun.

Further simulations will be carried out to include an investigation of its performance at different beam voltage, current and the sensitivity of the tolerance on these critical geometric parameters to the formation of a large orbit annular electron beam from the cusp electron gun.

IV. ACKNOWLEDGMENTS

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