THE DEVELOPMENT OF NEW TERAHERTZ GENERATOR USING BEAM OPTICS AND RF DEFLECTOR

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Abstract

New terahertz (THz) generator using the non-relativistic electron beam was developed based on the beam optics and the RF deflector. The conventional THz generators using the electron beam are almost based on the relativistic beam to utilize the Lorenz factor as FELs or the strong magnet to make high electron density like gyrotrons or BWOs. Thus it causes that the total equipment becomes large. New THz generator uses the non-relativistic electron beam. And it consists of the beam optics which makes the sliced beam by using an anode slit to focus at second slit as the THz radiation plane. In this configuration, the RF deflector works to move for the transverse direction matched with the phase velocity of the radiated electromagnetic field. The moving sliced beam separates into a number of bunches through the second slit and the bunches makes the THz coherent radiation in zero time interval. In this new THz generator, no strong magnet is required and the large diameter beam can be utilized to generate the high power THz electromagnetic wave. In this paper, the design of new THz generator and its experimental results are reported.

INRODUCTION

Back ground

THz is expected to apply for wider areas, just as terabit communication sources, less damage imaging devices for medicines or securities, high molecular analytical equipment for biology or pharmacy, and so on.

However, there is no established method for generating THz radiation. The method using the electron beam is one of them. In general, one of the advantages using electron beam is capability to generate high power electromagnetic wave.

The conventional THz generators using the electron beam need large-scaled apparatus to solve space charge. For example, to solve these problems, FELs consist of an accelerator, gyrotrons or BWOs employ strong magnets whose magnetic field of over 1 Tesla.

This problem is caused by keeping the short bunches or holding the thin beam, during an interaction between the electron beam and the electromagnetic wave.

In this paper, small size THz generator without an accelerator or any strong magnets is reported.

TERAHERTZ GENERATOR

Overview

This THz generator using the non-relativistic electron beam based on its beam optics and the RF deflector is designed using the simulations of the beam optics, the electromagnetic field, and the particles.

Figure 1: A whole picture of THz generator

For solving the problems as described in the preceding chapter, it is important to take no time from making the bunches to generating electromagnetic wave. This method is that the original beam is screened periodically by a conductor slit. And the electromagnetic wave is generated by the beam in no time as follows.

The electron beam emitted from a LaB6 cathode is accelerated to the energy of 10 keV between a cathode and an anode. Sliced beam is made when it passes through the mesh which is mounted after the anode. The beam which passes through the anode mesh is deflected and is swept on another mesh (Generator mesh). Then the passing beam is bunched. It is able to generate the electromagnetic wave of the low frequency RF with a sweep frequency and a sweep width.

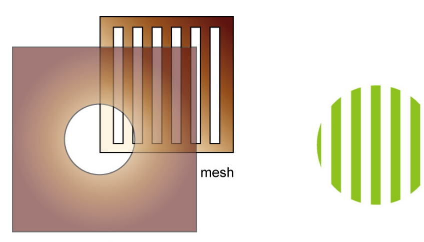

Figure 2: The configurations of an anode and a cathode mesh (left) . A shape of the electron beam cross-section right after passing through the anode mesh (right)

Next section introduces elements of the THz generator in this experiment.

Large-area LaB6 filament cathode

In this experiment, the LaB6 is used for the cathode since it is stable in the air and is easy to handle for such an experiment. This material has the moderate resistance. The LaB6 cathode can heat by applying the current.

And a filament-shaped poly crystal is adopted for the cathode since this method can use large cross-section area beam. In a lot of cases, a single crystal is used as a heat cathode: less than $1mm^3$. And LaB6 is heated by an additional carbon heater.

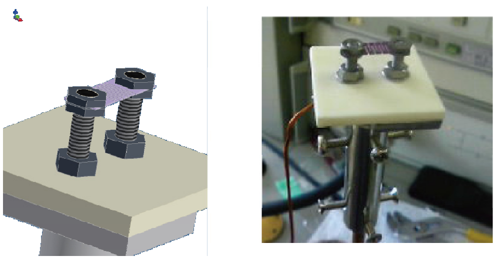

Figure 2: A drawing of the LaB6 filament cathode(left) A picture of the developed LaB6 filament cathode(right)

The filament type cathode is better than cathode employed a heater, in this case. Because, the LaB6 cathode requires to heat up to a higher temperature than other cathode materials to emit the electrons and it is difficult to heat by a heater.

The size of LaB6 is 7x15x1 mm^3. It has staggered eight slits of 6 mm lengths every 8.5 mm distances. And it is supported by two molybdenum clinchers of 3mm diameters.

RF deflector

The RF deflector is installed to deflect the electron beam.

The magnetic field is convenient to deflect the electron beam, because it can deflect beam trajectory without consumption of the RF power.

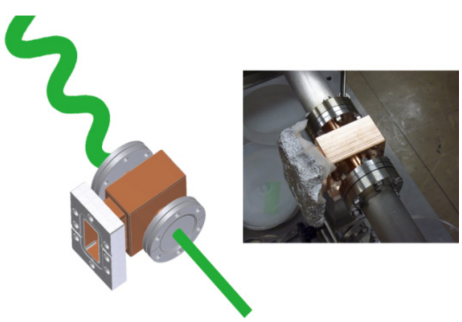

Figure3: A drawing of the RF deflector and the electron beam (left). A picture of the developed RF deflector (right)

In this experiment, the TM_{110} like mode is used for the deflector. In this mode, the electric fields do not exist in a center of the cavity. The electron beam is affected by the magnetic fields only and is deflected the distance of 10mm by the RF power of 400 W after the electron beam runs the distances of 1 m.

The electromagnetic field in this cavity is designed to tune at the resonant frequency.

Generator

The THz generator is a conductor plate with a mesh. It has a little space between the conductor and the mesh. This structure with the mesh, which covers the space for the THz electromagnetic waveguide, is adopted because the electron beam can pass the mesh but the electromagnetic wave keeps inside.

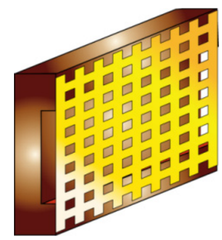

Figure 4: A drawing of the Generator

The bunched beam is made by sweeping the sliced beam on the generator mesh. The height of the THz waveguide is the distance of 0.5 mm between the conductor and the mesh.

Beam optics

For this THz generator, it is not required to hold the thin beam. It is important to produce an image of the beam right after the anode mesh on another focal plane.

The quadrupole magnet sets can be considered as the optical lenses. Thus the magnetic lenses can not only focus the electron beam but also produce an image.

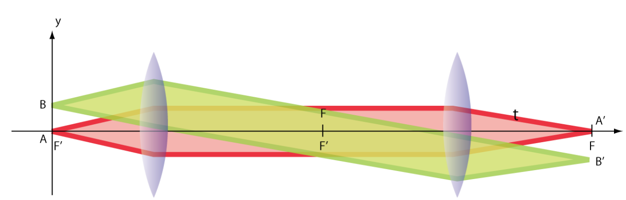

Figure 5: A conceptual diagram of the electron beam optics

The layout of the quadrupole magnets is decided considering the beam optics. The electron beam emitted from the focus of the lens becomes the parallel beam when it passes through the lens. And the parallel beam is focused when it passes through another lens. Finally, the same images are produced at each focus. It shows the layout of quadrupole magnets is decided that the anode mesh and the THz generator are employed at the focus of the lens each other.

The location of the RF deflector is decided too. The electron beam has information of location in the axis of y at the focus. And then, the electron beam becomes the parallel beam. This parallel beam's angle is decided by the location of y at the start focus. In addition, the location of y at the end focus depends on the beam angle. Therefore, it finds that the deflector should be employed between the two lenses to mostly affect the sweep width of the electron beam.

RESULTS AND DISCUSSION

Beam Optics Simulation

Figure 6 shows a simulation result using SAD. The two lines of the upper side show the diameters of the electron beam in the axis x and y. The two lines of the under side show the phase of the betatron oscillation in the axis x and y. And a bottom drawing shows the layout of the quadrupole magnets.

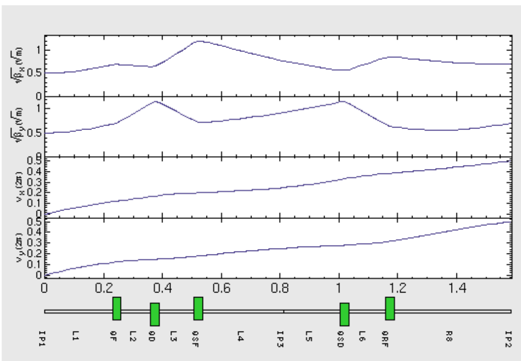

Figure 6: The beam optics simulation (SAD)

The layout of the quadrupole magnets is decided not to spread the electron beam within the beam pipe limits. In the Figure 6, while the beam diameters transition inside 2.4-times of the initial beam size, the beam diameters at the end point are unchanged from the start point. In addition, they show that the quadrupole magnets have no need to keep the thin beam, too.

Further the location of the RF deflector is decided by the phase of the betatron oscillation.The RF deflector should be employed at the location with severely-dependent on the angle of the parallel beam.

Particle Simulation

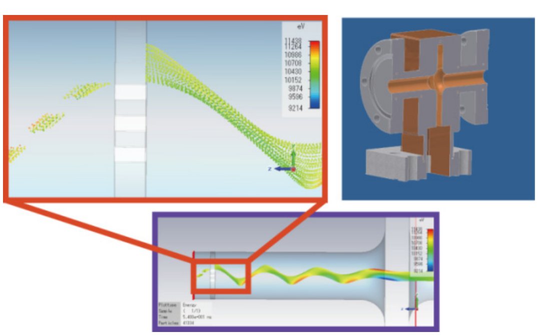

Figure 7: The particle simulation showing the bunched electron beam by the THz generator

Figure 7 shows that the electron beam is deflected when it passes through the RF deflector and the swept electron beam is bunched by the generator mesh. Some bunches is made when the electron beam pass through the THz generator mesh.

Parameters

The parameters in this experiment will be introduced in Table 1.

Table 1: Parameters in this simulation

Topic	Value
Generation Frequency	100 GHz (design value)
RF Frequency in deflector	5.712 GHz
RF Power	400 W
Sweep Width	10 mm
Beam Current	10 mA
Beam Emittance	1 mm.mrad

Experimental Results

The experiments are that measurement of the electron beam current and an observation of the images of the electron beam which is sliced or sweeping using a fluorescent plate. The beam current of 1.2 mA was measured at the generator. The beam optics is currently under adjustment. The additional magnetic lens may be required for more investigations.

CONCLUSIONS

- LaB6 filament cathode is useful in this experiment.
- Each element has been already installed.
- Simulation results suggest that some bunches for THz generation can be made by these processes.
- Electron beam passes through the beam optics to the THz generator. The beam optics elements will be refined to deflect the sliced beam as designed.

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