Design of Micrograting Structures for Laser Acceleration of Electrons

Ira S. Lehrman
Grumman Corporate Research Center
Princeton, NJ

Michael J. Arida
Rensselaer Polytechnic Institute
Troy, NY

Richard C. Fernow, Harold G. Kirk
Brookhaven National Laboratory
Upton, NY

Abstract

Preliminary modeling of micrograting structures indicate that gratings can be designed to support the π-mode for acceleration of $\beta \cong 1$ electrons.

I. Introduction

The next generation of linear colliders for high energy physics research will undoubtedly require accelerating gradients much greater than presently achievable today in order to be cost and size effective. A number of schemes have been proposed in the hopes of reaching accelerating gradients of 1 GeV/m[1]. To put this in perspective, a 20 TeV collider which utilized accelerating cavities with a gradient of 1 GeV/m would have a total length of 40 km, which is about half the circumference of the SSC. The same collider with conventional cavities providing 30 MeV/m gradient would have a length greater than 1300 km.

Experiments at the Accelerator Test Facility (ATF) at Brookhaven National Laboratory will investigate laser accelerating of electrons utilizing a short pulse CO_2 laser ($\lambda = 10.5\ \mu m$) as the power source and a micrograting structure as the accelerating "cavity." The advantage of such a scheme may be the high electric fields (~1 GeV/m) that the laser can provide. These short pulses are not expected to damage the micrograting structure. This system lends itself to synchronization easily since the ATF is equip with a laser driven photo-cathode gun.

The small size of these structures makes them difficult to diagnose, hence we have begun to model various micrograting structure using the 3-D SOS[2] particle-in-cell (PIC) code. These simulations consist of two separate processes to be modeled. First, we excite the modeled structure with a short electron bunch and observe the frequency response of the system. This process is analogous to Smith-Purcell radiation[3]. The dimensions of the structure are varied until the mode equal to the accelerating mode is optimized. The second process consists of sending a plane wave into the system to excite the micrograting structure, then injecting electrons and observing the acceleration.

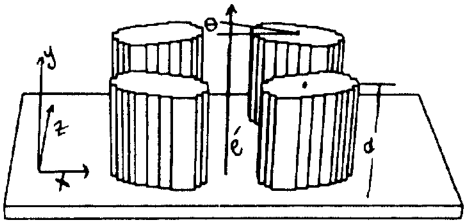

Figure 1. Collonade micrograting structure.

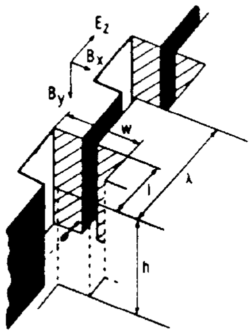

Figure 2. Foxhole micrograting structure.

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In this paper, we present preliminary simulation results for the first process of simulating these structures. Two structures were originally proposed for laser acceleration experiments, the so called collonade and foxhole microgratings show in Figures 1 and 2, respectively. Table 1 lists the dimensions for the collonade and foxhole structure. In addition to modeling both of these structures, an optimized micrograting structure resulted from this work which we believe possesses better characteristics than the originally proposed structures.

Dimension	Size (μm)
λ	10.5
Angle (collonade)	15°
d (collonade)	4.1
W (foxhole)	10.5
h (foxhole)	6.2
l (foxhole)	5.25
slot (foxhole)	2.0

Table 1. Dimension of the collonade and foxhole structures

II. Method

A difficulty with the laser acceleration technique is to induce an accelerating mode which is supported by the grating. This can be understood by examining the dispersion relation for an incident plane wave traveling in the y direction:

$$k_y^2 = \frac{\omega^2}{c^2}\,;\; k_x^2 = k_z^2 = 0$$

The condition for continuous acceleration of a $\beta \cong 1$ electron beam is $k_z^2 = \omega^2/c^2$. This leads to:

$$k_x^2 + k_y^2 = 0$$

This translates to evanescence in the y direction at the surface of the grating as well as inducing a set of modes in the x direction.

To determine which structures efficiently support the accelerating mode, the 3-D SOS PIC code was used. We model a short electron bunch passing through one or two periodic lengths of the grating and observe the resulting radiation. Metallic and freespace boundary conditions were used to simulate the extent of the micrograting. Fourier analysis of the radiation allows us to tune structures to support the desired mode. Tuning included changing the transverse dimensions of the structures as well as including walls symmetrically around the structure in the x direction. Typical simulation grids consisted of 42 cells in the direction of propagation (z), 32 cells to represent the height (y) of the structure, and 42 cells in the other transverse direction (x).

III. Results

Initially, freespace boundaries were included in the x planes at ± 10 μm to simulate the original designs of the collonade and foxhole gratings. The collonade structure did not exhibit radiation at the desired frequency. Varying the angle of the collonades had only a slight effect on the location of the peak frequency, but no angle resulted in the desired resonant frequency. Simulations of the foxhole indicated that a width of 10.5 μm resulted in a cavity mode being excited in this region. This mode has a zero crossing at $x = 0$ which is undesirable since it provides no acceleration along the axis of the grating.

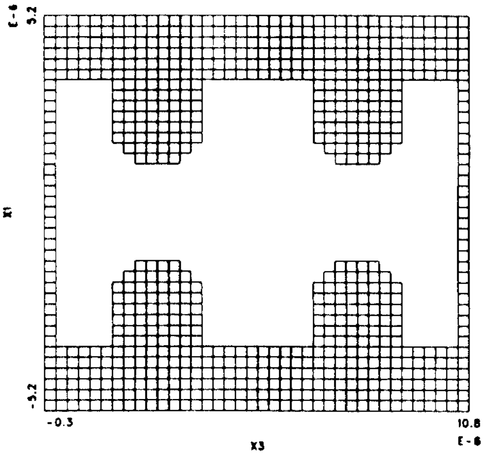

Figure 3. Geometry of the optimized micrograting Structure

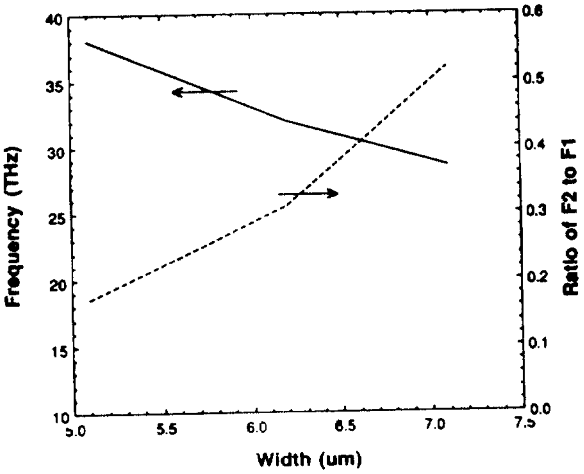

Figure 4. Resonant Frequency and Ratio of Second Resonant Frequency versus width.

By reducing the height of the foxhole structure to 4.1 μm, and putting metallic walls in the x planes spaced at the width of the structure, resonance was obtained. Figure 3 depicts this geometry. Figures 4 shows the resonant frequency and the ratio of the second resonant frequency to the primary frequency versus width. Figure 5 shows the Fourier transform spectrum for the optimized structure.

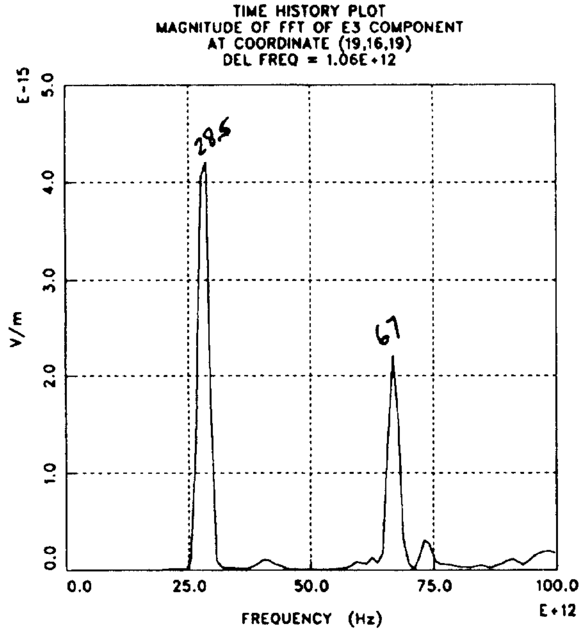

Figure 5. Fourier spectrum for the optimized structure

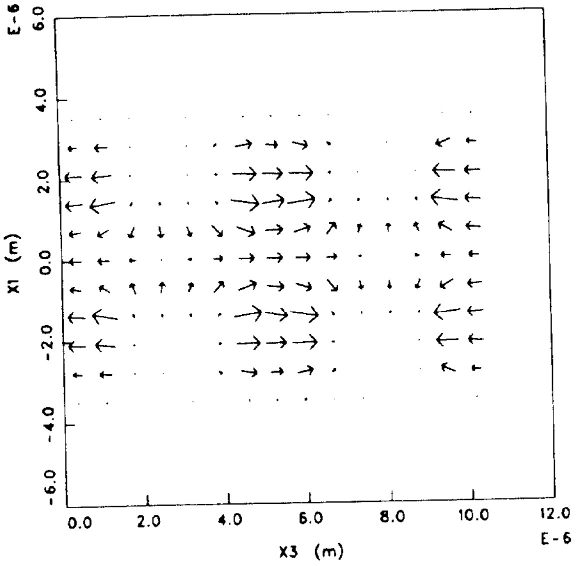

Figure 6. Vector plot of Ex-Ez showing for the optimized structure.

Placement of the walls results in a more efficient structure (higher Q) which can be made to resonant at the desired frequency. Notice that the structure resembles both the collonade and foxhole designs. Figure 6 is a vector plot of the electric fields clearly showing the π-mode for acceleration.

IV. Conclusions

A preliminary study of micrograting structures indicates that with proper design a micrograting can be constructed with will preferentially support the mode for resonant acceleration of $\beta = 1$ electrons. In the future, we will investigate these structures in a more carefull manor. We will then carry out the second simulation approach in which we excite the structures with incoming radiation and determine the effective acceleration. This should allow us to determine if 1 GeV/m gradients are realistic for this method of acceleration.

References

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[3] S. J. Smith and E. M. Purcell, Phys. Rev. **92** (1953) 1069.