

LETTER

Efficiency Enhancement in a Rectangular Cherenkov Laser by a Proper Variation of Dielectric Permittivity in the Transverse Direction

Sirou HIROSAKA^{†a)}, Nonmember, Akimasa HIRATA[†], Student Member, and Toshiyuki SHIOZAWA[†], Member

SUMMARY In order to enhance the energy transfer efficiency in a rectangular Cherenkov laser, we propose to vary properly the permittivity of a loaded dielectric in the transverse direction. With the aid of particle simulation, we investigate the amplification characteristics of the rectangular Cherenkov laser with a dielectric permittivity varied in the transverse direction, demonstrating the effectiveness of our proposal for efficiency enhancement.

key words: Cherenkov laser, transverse permittivity variation, efficiency enhancement, particle simulation

1. Introduction

The Cherenkov laser is a potential high-power and tunable source of short millimeter or submillimeter waves. In the Cherenkov laser, the kinetic energy of a relativistic electron beam is converted into the electromagnetic (EM) energy through the active coupling between a relativistic electron beam and a slow EM wave propagated along a dielectric-loaded waveguide. In recent years, a three-dimensional (3-D) model of a Cherenkov laser using a dielectric-loaded rectangular waveguide was analyzed with the aid of particle simulation [1]. In the previous paper, the energy transfer rate in the 3-D case was found to become smaller than that for the 2-D case [2]. The main reason for this is that the electric field acting on the electron beam is nonuniform in the transverse direction. This difficulty could be improved if the nonuniformity in the electric field is flattened. Thus we propose to vary properly the permittivity of a loaded dielectric in the transverse direction in order to flatten the nonuniform transverse distribution of the electric field. The purpose of this letter is to demonstrate the effectiveness of this scheme for efficiency enhancement in the energy transfer from the electron beam to the EM wave in the Cherenkov laser, with the aid of particle simulation [1]–[4].

2. Numerical Results

The geometry of the problem is shown in Fig. 1, together with the coordinate system. The 3-D Cherenkov

laser under consideration consists of a rectangular waveguide, the lower inner surface of which is loaded with a dielectric sheet, and a finite-width planar relativistic electron beam drifting through the waveguide. The electron beam is assumed to be ion-neutralized and magnetically confined in the z direction by a sufficiently large magnetostatic field.

The values of various parameters used in the numerical simulation are as follows: the thickness of a dielectric sheet $a = 0.5$ mm, the beam-dielectric gap $b - a = 0.5$ mm, the beam thickness $d - b = 0.5$ mm, the inner height of waveguide $f = 2.0$ mm, the beam-waveguide gap $g = 1.0$ mm, and the beam width $h - 2g = 8.0$ mm. We choose the initial drift velocity of the electron beam normalized by the speed of light in vacuum $\beta_0 = 0.8274$, the electron number density $n_0 = 2.01 \times 10^{10}/\text{cm}^3$, the relative permittivity of the dielectric $\epsilon_r = 2.12$, and the guide wavelength $\lambda_g = 2.0$ mm. In addition, the variation of relative permittivity ϵ_r' is assumed to be represented as

$$\epsilon_r' = \epsilon_r + \alpha_c \left(x - \frac{h}{2} \right)^2 \quad (1)$$

where α_c is an arbitrary coefficient. Note that ϵ_r' is assumed to be uniform in the y and z directions.

We show in Fig. 2 how the transverse distribution of the longitudinal electric field for the dominant mode, which is closely associated with the interaction with the electron beam, depends on the values of α_c . As is evi-

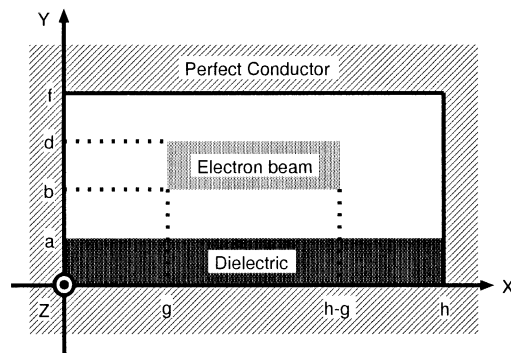


Fig. 1 Geometry of the problem.

Manuscript received April 7, 1999.

[†]The authors are with the Graduate School of Engineering, Osaka University, Suita-shi, 565-0871 Japan.

a) E-mail: hirosaka@comm.eng.osaka-u.ac.jp

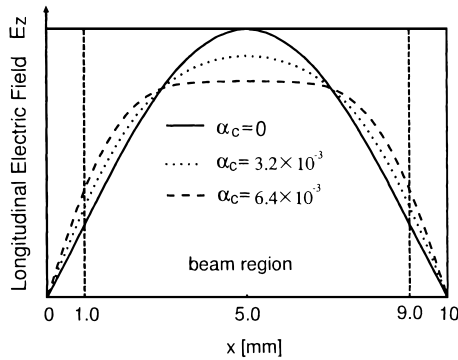


Fig. 2 Electric field distributions in the transverse direction for $\alpha_c = 0, 3.2 \times 10^{-3}$, and 6.4×10^{-3} .

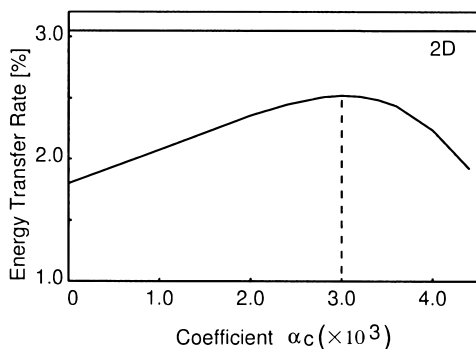


Fig. 3 The rate of energy transfer at $z = 1.4$ m.

dent from Fig. 2, the nonuniformity in the electric field distribution is flattened as the coefficient α_c becomes larger. However, it is expected that the interaction distance becomes longer, since the maximum value of the electric field becomes smaller with increasing α_c . Thus we choose the reference position for the following discussion at $z = 1.4$ m, where the rate of energy transfer [3] has the maximum value for a uniform dielectric permittivity, i.e., $\alpha_c = 0$.

We plot in Fig. 3 the rate of energy transfer at $z = 1.4$ m versus the coefficient α_c . From Fig. 3, the rate of energy transfer at $z = 1.4$ m has the maximum value at $\alpha_c = 3.0 \times 10^{-3}$. Thus, for the value $\alpha_c = 3.0 \times 10^{-3}$, we illustrate in Fig. 4 the spatial variation of energy transfer rate. As is evident from Fig. 4, the proper permittivity variation in the transverse direction leads to appreciable enhancement in the amplification characteristics for the Cherenkov laser. The rate of energy transfer at $z = 1.4$ m is found to be 1.8% for a uniform permittivity while it is enhanced to 2.5%

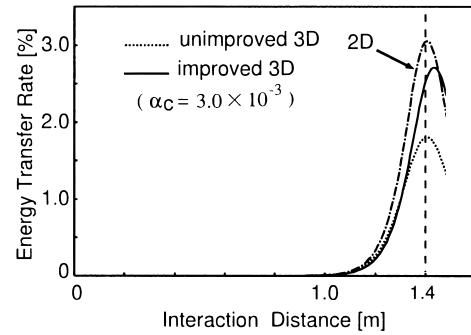


Fig. 4 Spatial variation of the energy transfer rate.

for the properly varied permittivity distribution. This enhancement is caused by the flatness in electric field distribution, as mention above.

3. Conclusion

With the aid of particle simulation, we discussed the efficiency enhancement in a rectangular Cherenkov laser, in which the permittivity of a dielectric sheet constituting the waveguide was properly varied in the transverse direction. Numerical results show that the rate of energy transfer from the electron beam to the EM wave is appreciably enhanced by properly varying the permittivity of the dielectric sheet.

Acknowledgement

We would like to thank Mr. Y. Yuse and Mr. H. Tokunaga for valuable discussions.

A part of this work was supported by the grant-in-aid for Scientific Research of the Ministry of Education, Science, Sports and Culture of Japan.

References

- [1] A. Hirata and T. Shiozawa, "Three-dimension analysis of a Cherenkov laser via particle simulation," *IEEE J. Quantum Electron.*, vol.34, pp.1802–1806, 1998.
- [2] K. Horinouchi, M. Sanda, H. Takahashi, and T. Shiozawa, "Analysis of a Cherenkov laser via particle simulation," *IEICE Trans.*, vol.J78-C-1, pp.1–8, Jan. 1995.
- [3] T. Shiozawa and T. Yoshitake, "Efficiency enhancement in a Cherenkov laser loaded with a Kerr-like medium," *IEEE J. Quantum Electron.*, vol.31, pp.539–545, 1995.
- [4] C.K. Birdsall and A.B. Langdon, *Plasma Physics via Computer Simulation*, McGraw-Hill, New York, 1985.