Optical emitter and amplifier by utilizing traveling electron beam

Optical Emitter and Amplifier by Utilizing Traveling Electron Beam

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Abstract : A scheme of optical emission and amplification by utilizing traveling electron beam with a high refractive index waveguide in a vacuum was theoretically predicted and experimentally confirmed. Experimentally observed characteristics were compared with theoretical examinations.

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Introduction

Lasers are principal devices in opto-electronics and contributed for development of advanced technologies. However, we have to find out new lasing material if we require an operation in new optical frequency. Further more, conventional lasers have symmetric property between amplifications of the forward and backward propagating lights. This symmetric property restricts to realize a logical circuit and to construct a multifunctional optical system.

We had theoretically proposed a scheme for the optical amplification by using a traveling electron beam and a high refractive index waveguide in a vacuum to resolve above mentioned subjects,[1,2] and experimentally observed optical amplification for an incident light.[3] In this paper, we show the optical emission and amplification basing on almost same scheme with previous experiment but has not incident light.

Configuration of the experiment and mechanism of the optical emission and amplification

An electron gun and a slab type optical waveguide are installed in a vacuum chamber as illustrated in Fig.1. The waveguide is designed to guide the fundamental TM (Transverse Magnetic) mode with a velocity of $v_{opt} = c/n_{eff}$ and to penetrate the longitudinal electric field component into the vacuum.

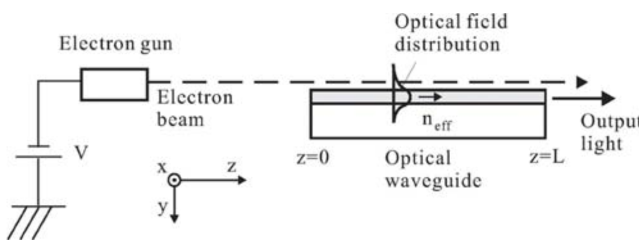

Fig.1 Configuration of the optical emitter

An electron beam is emitted from the electron gun and runs along surface of the optical waveguide with a velocity of v_e. When two velocities coincide as $v_e = v_{opt}$, the optical emission and amplification are generated.

Mechanism of the optical emission and amplification are understood by help of the energy diagram of an electron in a vacuum as shown in Fig.2, where the traveling electron is supposed at the energy level *b* as the initial state. When the electron transits to the lower level *a*, the optical emission and amplification are obtained. Keeping the energy and the momentum conservation rules between the transit electron and the optical field provides the condition of $v_e = v_{opt}$

Even there is no measurable optical field, the electron can transit by help of the zero-point field energy. We named this type of optical emission as the guided spontaneous emission, because the optical emission is possible only into the TM modes holding the condition of $v_e = v_{opt}$.

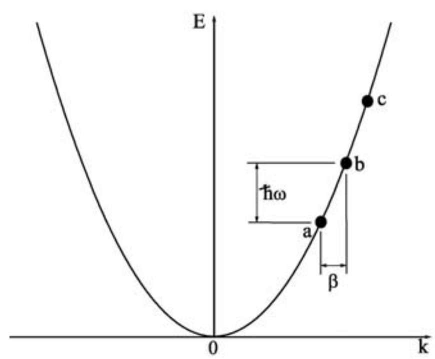

Fig.2 Energy diagram of an electron

Experimental observation

The electron gun used in our experiment has a variation range of the acceleration voltage from 30 to 50KV, and the maximum emission current is 50μm. The waveguide was prepared with the co-called SOI substrate consists of Si-SiO_2-Si layers, where the top Si layer was used as the core layer and the SiO_2 layer was used as a cladding layer. The thickness of the top Si layer was 0.32μm whose value was chosen to give suitable guiding characteristics in the wavelength range from 1.2 to 1.6μm.

Observed spectral profiles of the emitted light for several acceleration voltages are shown in Fig.3. The peak

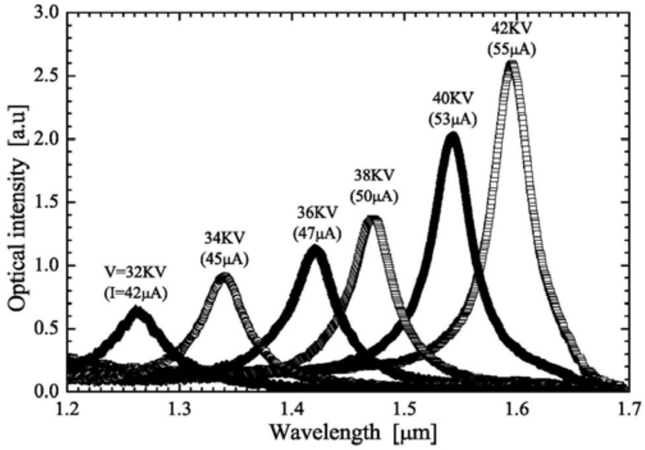

Fig.3 Emitted profiles

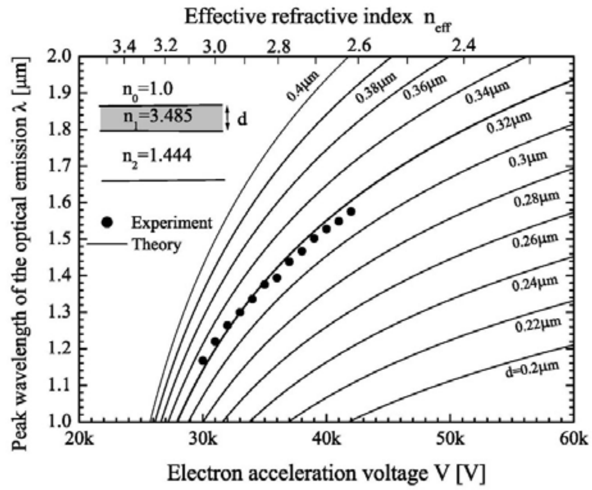

Fig.4 Wavelength vs. acceleration voltage

wavelength shifts to longer wavelength side with increasing of the acceleration voltage. This shift comes from change of the effective refractive index n_{eff} in the waveguide with the wavelength. Theoretically calculated variations of the emission wavelength with the acceleration voltage are shown in Fig.4 with solid lines, while experimental data are assigned with filled circles. The experimental data well coincide with the theoretical calculations.

The coherent length of the electron wave is an important parameter to analyze emission mechanism. By comparing the spectral width of the emitted light with the theoretical calculation, we estimated the coherent length of an electron wave in our experiment is around 40μm. This value just coincides with the separating distance of electrons which is given by the value of $1/N^{1/3}$ with the electron density *N* of the electron beam.

The spectrum width was narrowed by increasing the emission current. This property is evidence that both the guided spontaneous emission and the stimulated emission are generated with increase of the electron current.

Conclusions

We observed an optical emission and amplification basing on a new scheme by utilizing the traveling electron beam with a high refractive index waveguide in a vacuum. Experimentally obtained data well support our theoretical predictions. The coherent length of an electron wave in the vacuum was estimated to coincide with the separating distance of electrons.

Our scheme of the optical amplification must be applicable in extremely wide frequency range of the electro-magnetic wave such as from the microwave region to the X-ray region in principle.

References

1 M.Yamada, IEEE J. of Quantum Electron., **35**(1999), 147
2 M.Asada and M.Yamada, J. Appl. Phys., **95**(2004) 5123
3 Y.Kuwamura et al. Jpn. J. Appl. Phys., **43**(2004) 7109

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Yuji Kuwamura received the B.S. and M.S. degrees in electronics engineering from the Tokushima University in 1981 and 1983, respectively. He joined NEC corporation in 1983 and moved to Kanazawa University in 1987, where he is now a lecturer. He has been engaged in research on laser diodes, semiconductor optical modulators and optical amplifier by utilizing the electron beam. He holds a Ph.D. degree.