EXPERIMENTAL STUDY OF VOLUME FREE ELECTRON LASER USING A "GRID" PHOTONIC CRYSTAL WITH VARIABLE PERIOD

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Abstract

Experimental Study of Volume Free Electron Laser with a "grid" resonator ("grid" photonic crystal) with changing in space parameters are reported.

INTRODUCTION

Generators using radiation from an electron beam in a periodic circuit (traveling wave tubes [1,2], backward wave oscillators, free electron lasers) are now widespread [3].

All the above devices use one-dimensional feedback, which is formed by either two parallel mirrors placed on the both sides of working area or a diffraction grating.

But there are some challenges that restrict applications of such devices: electrical endurance of resonator limits radiation power and current of acceptable electron beam. Conventional waveguide systems are essentially restricted by the requirement for transverse dimensions of resonator, which should not significantly exceed radiation wavelength.

The indicated problems can be overcome by the aid of volume (non-one-dimensional) multi-wave distributed feedback [4–10]. New type of radiation generators using volume multi-wave distributed feedback was called Volume Free Electron Laser (VFEL). Transverse dimensions of VFEL resonator could significantly exceed radiation wavelength. The electron beam and radiation power are distributed over the large volume that is beneficial for electrical endurance of the system.

One of the VFEL types uses a "grid" photonic crystal that is formed by a periodically strained either dielectric or metallic threads, which provides to weaken requirements for beam guiding.

The "grid" structure of dielectric threads was experimentally studied in [11], where it was shown that such "grid" photonic crystals have sufficiently high Q-factor ($10^4 - 10^6$).

Theoretical analysis [12, 13] showed that periodic metal grid does not absorb electromagnetic radiation and the "grid" photonic crystal, made of metal threads, is almost transparent for the electromagnetic waves in the frequency range from GHz to THz. (In this range the skin depth δ is about 1 micron or less for the most of metals (for example, for 10 GHz $\delta_{Cu} = 0.66$ μm, $\delta_{Al} = 0.8$ μm, $\delta_W = 1.16$ μm and so on). Thus, in this frequency range the metallic threads can be considered as perfect conducting.)

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Theory of VFEL with spatially variable period was developed in [16, 17]. There it was shown that use of photonic crystal with variable period could provide significant increase in radiation output. It was mentioned that diffraction gratings (photonic crystal) can be used for creation the dynamical wiggler with variable period in the system. This makes possible to develop double-cascaded FEL with variable parameters changing, which efficiency can be significantly higher that of conventional system.

In the present paper experimental study of Volume Free Electron Laser with a "grid" resonator ("grid" photonic crystal) with changing in space parameters are considered.

EXPERIMENTAL SETUP

The "grid" photonic crystal is built from tungsten threads with the diameter 0.1 mm strained inside the rectangular waveguide with the transversal dimensions $a = 35$ mm, $b = 35$ mm and length 300 mm (see Fig.1). A pencil-like electron beam with the diameter 32 mm, energy up to 200 keV and current about 2kA passes through the above structure. The magnetic field guiding the electron beam is $\sim 1.55 - 1.6$ tesla. Period of "grid" photonic crystal is chosen to provide radiation frequency ~ 8.4 GHz. The "grid"

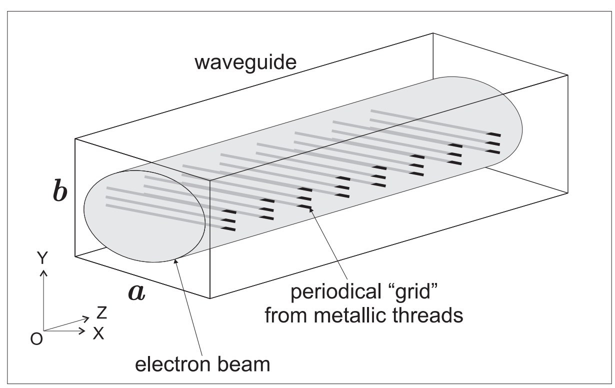

Figure 1: The "grid" diffraction grating placed inside the waveguide

structure is made of separate frames each containing the layer of 1, 3 or 5 parallel threads with the distance between the next threads $d_y = 6$ mm). Frames are joined to get the "grid" structure with the distance d_z between layers.

Frequency range is evaluated by means of tunable waveguide filters, which were tuned in the band 7.8 - 12.4 GHz with passbands 0.25 GHz, 0.5 GHz and 1 GHz. Attenuation of radiation in the suppressed band of this filter is ~ -25 dB.

Evaluation of ”grid” heating by electron beam action provides to expect long-time stability. For example, change of the thread temperature (tungsten threads of 100 μm diameter) due to action of the 250 keV electron beam with diameter 32 mm, current 1 kA and pulse duration 100 nsec can be estimated as $\Delta T < 125°$. Experiments with VFEL with the different ”grids” have demonstrated stability of developed photonic crystals to heating caused by electron beam action.

EXPERIMENTAL RESULTS

In the experiments [14] generation in the ”grid” VFEL was observed in BWO regime.

The sample oscillogram is shown in Fig.2, where signals marked 1 and 2 are the signals obtained from microwave detectors. Other two curves are the electron gun voltage and electron beam current. Time scale is 80 ns.

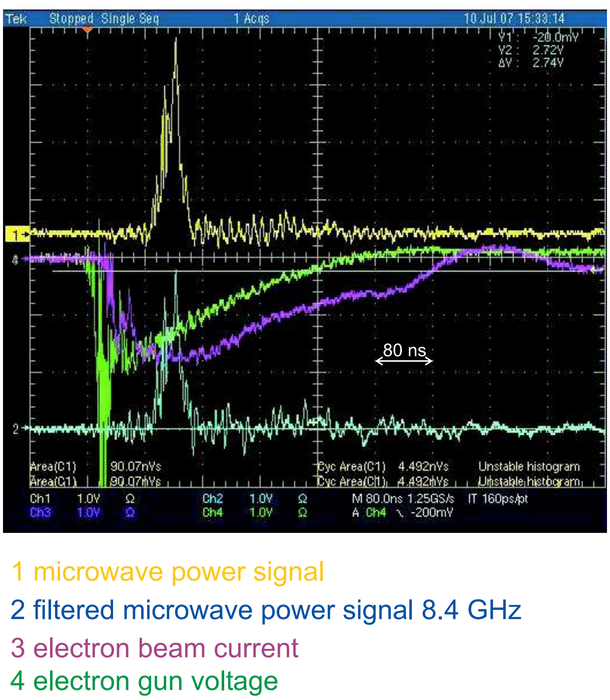

Figure 2: The sample oscillogram

The radiation power is measured for photonic crystal with 4, 6, 10, 12, 14 and 22 frames (period $d_z = 12.5$ mm) each containing five threads distant $d_y = 6$ mm each from other.

The result of these measurements is presented in Fig.3, where the radiation power is normalized to the maximal detected power (10 kiloWatt). Dependence of the generated radiation intensity on the ”grid” photonic crystal length is obtained. The solid curve in this figure shows the numerically simulated radiation power, which also normalized. It can be seen from this Figure that for the photonic crystal with more than 14 periods ($\sim 3 \cdot \lambda$) saturation is reached.

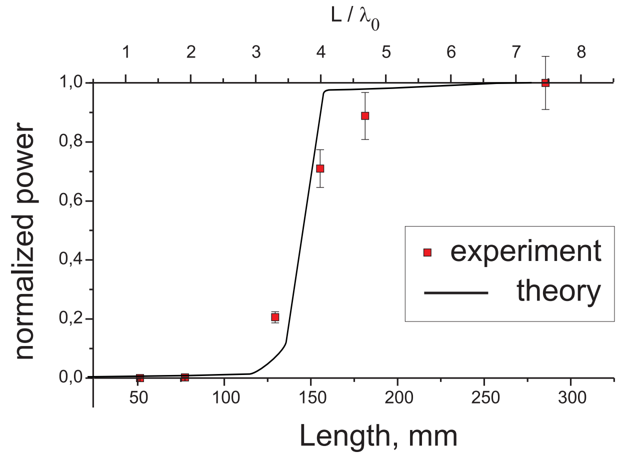

Figure 3: Dependence of the generation intensity on the length of the ”grid” photonic crystal with 5 threads in the frame marked with squares and numerically simulated dependence of the wave amplitude on the ”grid” photonic crystal length for the electron beam with the energy $\sim$200 keV and current density $\sim$ 2 kA/cm^2

The next experiment uses ”grid” resonator made of two photonic crystals with different periods. The ”grid” structure is made of separate frames each containing the layer of 5 parallel threads with the distance between the next threads dy=6 mm), 12 frames were joined to get the ”grid’ photonic crystal with the period 12.5 mm and another 12 frames formed ”grid’ photonic crystal with the period 10.5 mm . Total resonator length is 300 mm (the same as in the previous experiment). Separate experiments with the first photonic crystal (period 12.5 mm, 12 frames) were done to determine how the electron beam energy reduces after passing it. Period of the second photonic crystal is chosen to provide for the electron beam, which have lost part of its energy for radiation in the first photonic crystal, the same radiation frequency. Distance between two photonic crystals is 25 mm. The typical oscillogram for this experiment is shown in Fig.4.

Two radiation peaks are apparent in this oscillogram. Measurements of radiation frequency gives value close to 8.4 GHz for both peaks. Their intensities are also comparable and detected power is almost twice higher then that for the experiments with ”grid” photonic crystal with 5 threads in the frame and fixed period.

Experimental results confirmed conclusion that photonic crystal with variable period could increase radiation output. Experiments are in progress.

Several experiments with Volume Free Electron Laser with the ”grid” photonic crystals in millimeter and submillimeter wavelength ranges are in preparation now.

In the experiment with 200 keV electron beam radiation in the range 4-5 mm is expected to be observed. This experiment will be carried out in the Research Institute for Nuclear Problems (INP, Minsk, Belarus) for the ”grid” photonic crystal, built from periodically strained tungsten

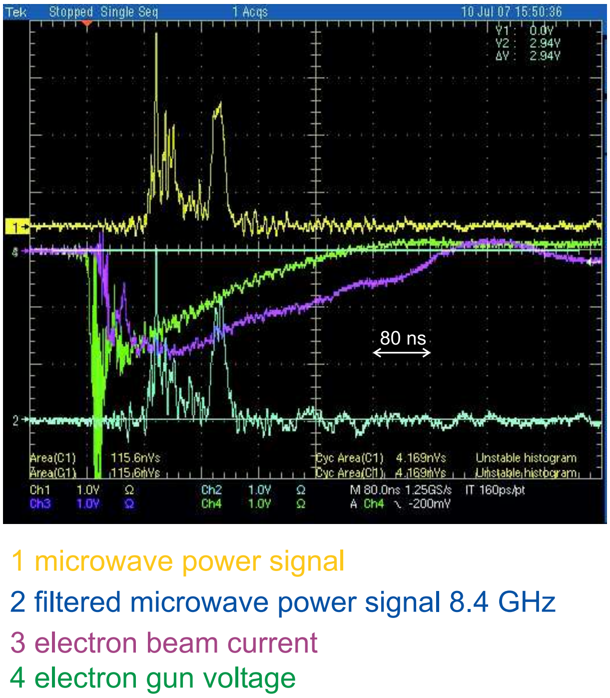

Figure 4: Typical oscillogram for ”grid” resonator made of two photonic crystals with different periods

threads in the waveguide.

Joint experiment is being prepared now by INP and Joint Institute for Nuclear Research (JINR, Dubna, Russia) at LINAC-800, where 6 MeV electrons will be used for generation of radiation with mm and mm (150 GHz and 1 THz, respectively).

Realization of VFEL with dynamical wiggler (and conventional wiggler) with spatially varied period is also in our nearest plans.

CONCLUSION

Experimental results confirmed conclusion that photonic crystal with variable period could increase radiation output. Experiments are in progress.

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