Experimental Study of Volume Free Electron Laser using a "grid" photonic crystal with variable period

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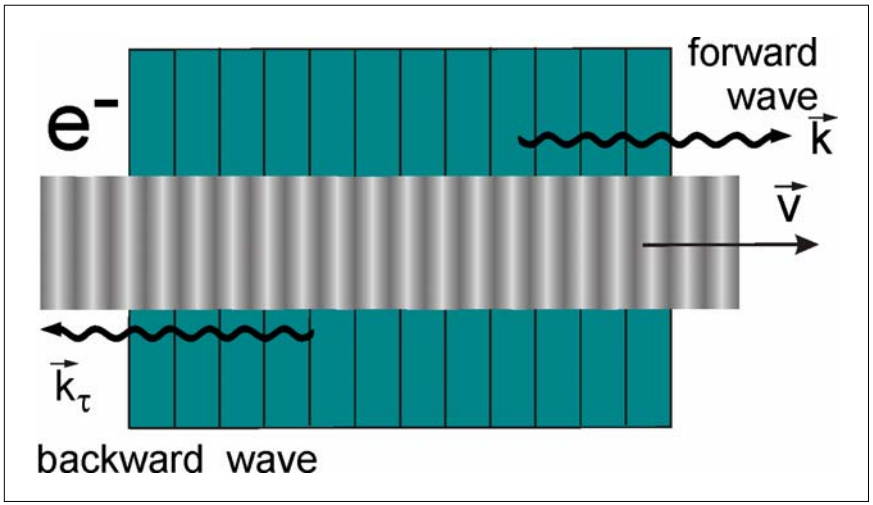
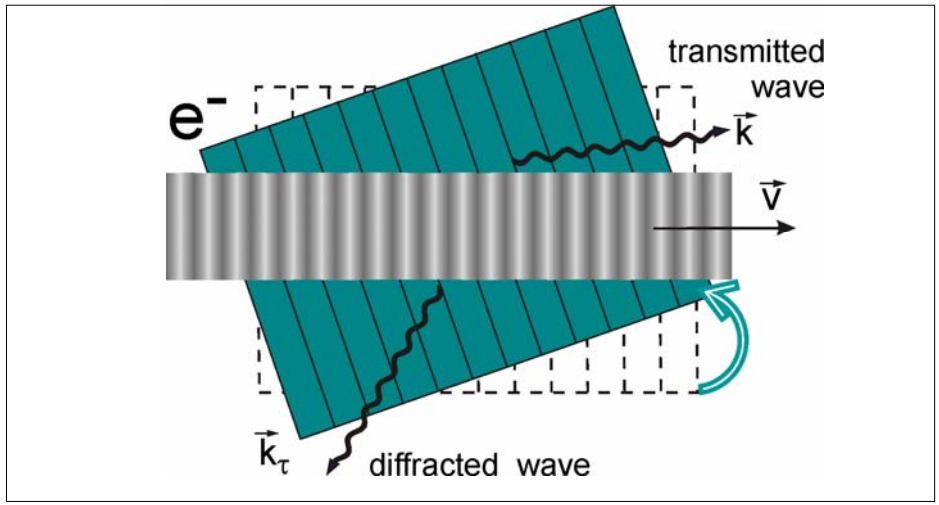
What is volume distributed feedback ?

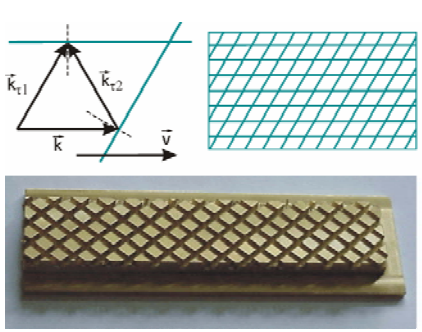
Volume (non-one-dimensional) multi-wave distributed feedback is the distinctive feature of Volume Free Electron Laser (VFEL)

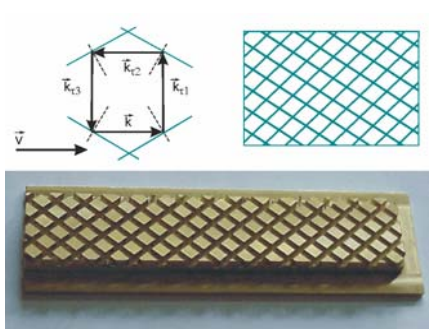
one-dimensional distributed feedback

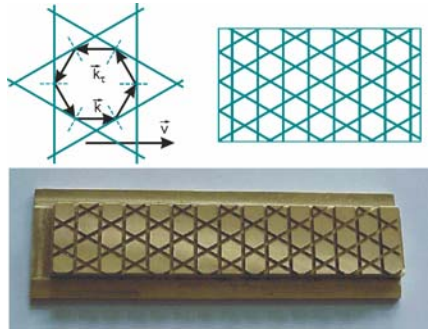


two-dimensional distributed feedback





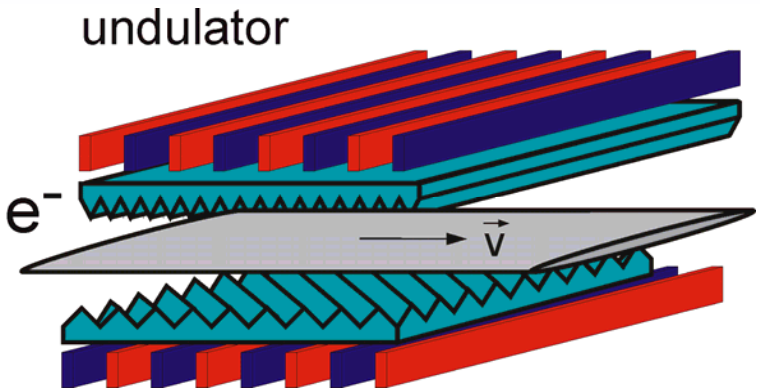




Use of volume distributed feedback makes available:

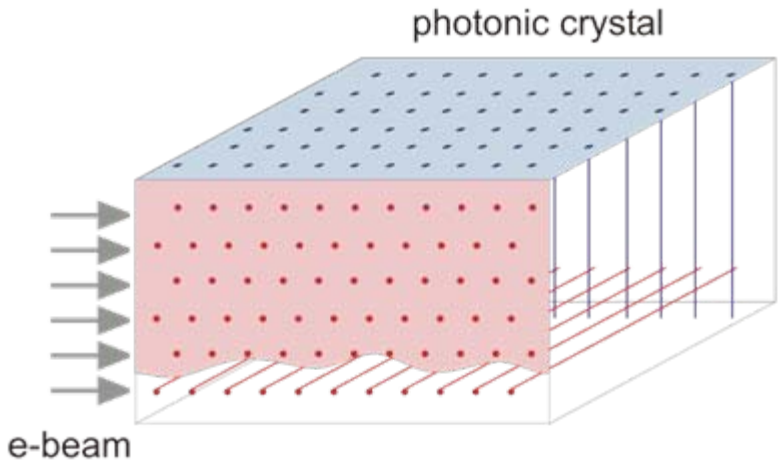
- ✓ frequency tuning at fixed energy of electron beam in significantly wider range than conventional systems can provide
- ✓ more effective interaction of electron beam and electromagnetic wave, which leads to significant reduction of threshold current of electron beam and, as a result, miniaturization of generator
- ✓ reduction of limits for available output power by the use of wide electron beams and diffraction gratings of large volumes
- ✓ simultaneous generation at several frequencies

Types of Volume Free Electron Laser ? *



VFEL can use any spontaneous radiation mechanism (magnetic bremsstrahlung in undulator, radiation in laser wave, Smith-Purcell, diffraction or Cherenkov radiation and so on).

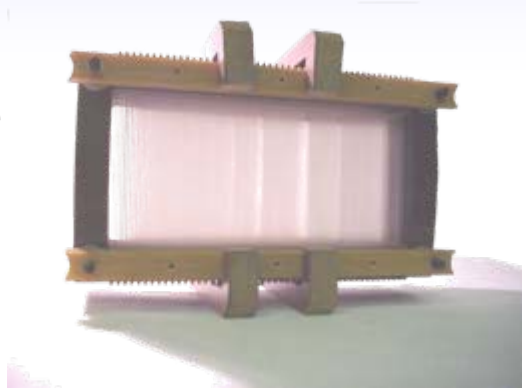
One of the VFEL types uses a “grid” volume resonator (”grid” photonic crystal) that is formed by a periodic structure built from either dielectric or metallic threads



* Eurasian Patent no. 004665

VFEL experimental history

1996



Experimental modeling of electrodynamic processes in the volume diffraction grating (photonic crystal) made from dielectric threads

V.G.Baryshevsky, K.G.Batrakov, I.Ya. Dubovskaya, V.A.Karpovich, V.M.Rodionova, *NIM 393A (1997) 71*

2001

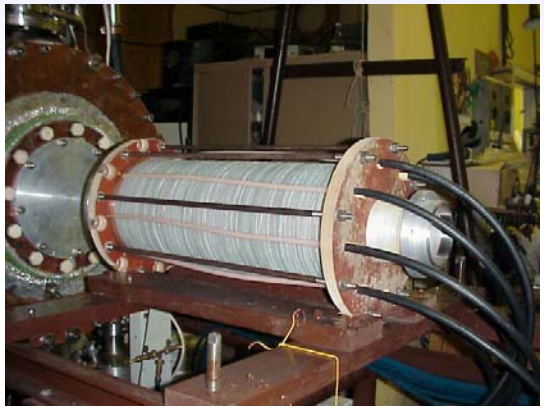
First lasing of volume free electron laser in mm-wavelength range. Demonstration of validity of VFEL principles. Demonstration of possibility for frequency tuning at constant electron energy

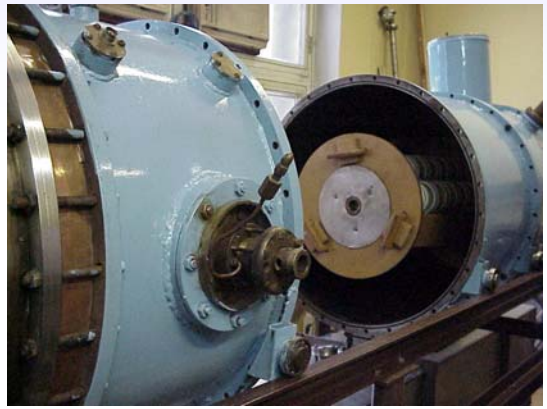
V.G.Baryshevsky, K.G.Batrakov,A.A.Gurinovich, I.I.Ilienko, A.S.Lobko, V.I.Moroz, P.F.Sofronov, V.I.Stolyarsky, *NIM 483 A (2002) 21*

2004

New VFEL prototype with volume photonic crystal as resonator

Volume Free Electron Laser at Research Institute for Nuclear Problems



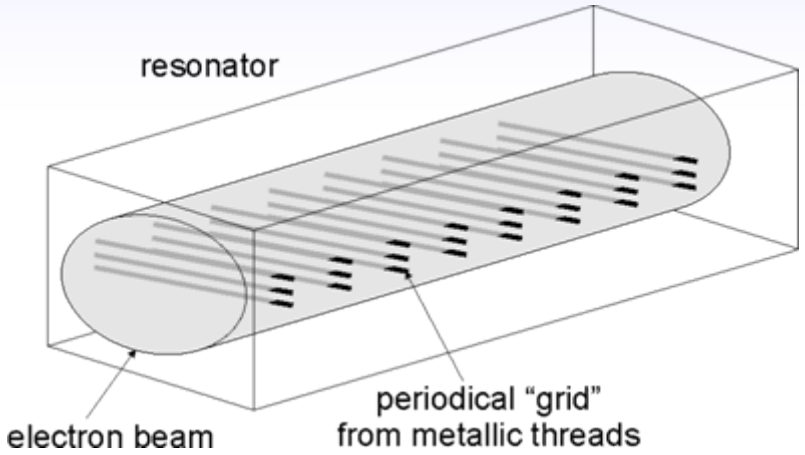


Main features:

- “grid” photonic crystal as resonator
- electron beam of large cross-section
- electron beam energy 100-500 keV

Electrodynamical properties of a "grid" photonic crystal *

Electrodynamical properties of a volume resonator that is formed by a perodic structure built from the metallic threads inside a rectangular waveguide are considered.



Theoretical analysis* 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.

* **Baryshevsky V.G., Gurinovich A.A**. Spontaneous and induced parametric and Smith–Purcell radiation from electrons moving in a photonic crystal built from the metallic threads // Nucl. Instr. Meth. B. Vol.252. (2006) P. 92-101, physics/0409107

Thread heating evaluation

- tungsten threads of 100μm diameter
- electron beam energy 250 keV
- electron beam current 1 kA
- pulse duration 100 nsec
- electron beam diameter 32 mm

- $6 \cdot 10^{14}$ electrons in the beam
- $2 \cdot 10^{12}$ electrons passes through a thread
- 0.08 Joule transferred to the thread

if suppose that all electrons passing through the thread lose the whole energy for thread heating

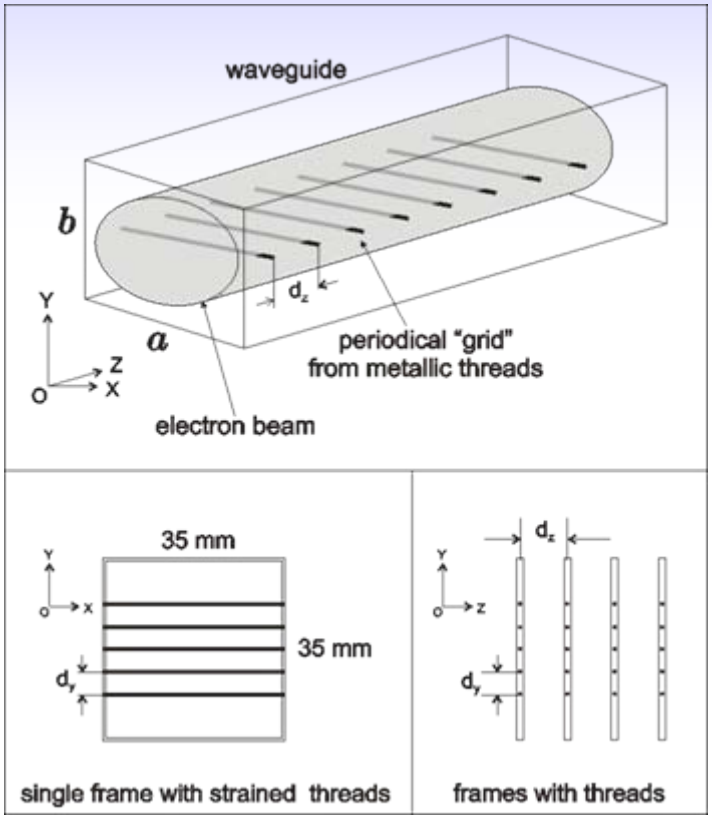
$$\Delta T < 125°$$

VFEL with spatially variable parameters

Theory of VFEL with spatially variable period was developed in [1,2]. 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.

[1] V.G.Baryshevsky, A.A.Gurinovich. arXiv: physics/0608068
[2] V.G.Baryshevsky, A.A.Gurinovich. in *Proceedings of FEL 2006*, BESSY, Berlin, Germany, pp.335-339 (2006).

Experiments with “grid” VFEL



The "grid" 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.

electron beam energy about 200 keV

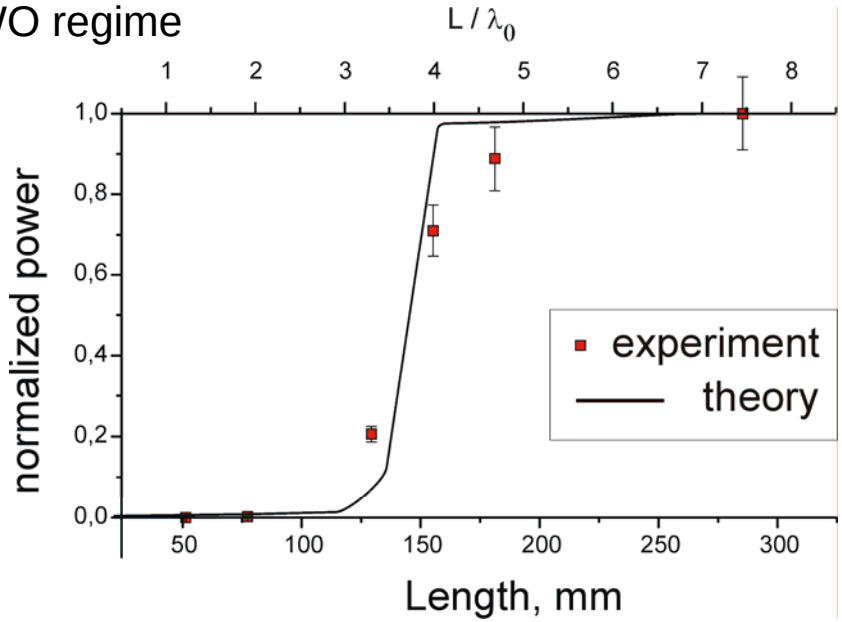
electron beam current 2kA

pencil-like electron beam with the diameter 32 mm

magnetic field guiding the electron beam is 1.55 - 1.6 tesla.

radiation frequency about 8.4 GHz.

BWO regime



Dependence of radiation power on resonator length

“Grid” VFEL with constant period

microwave power signal

electron gun voltage

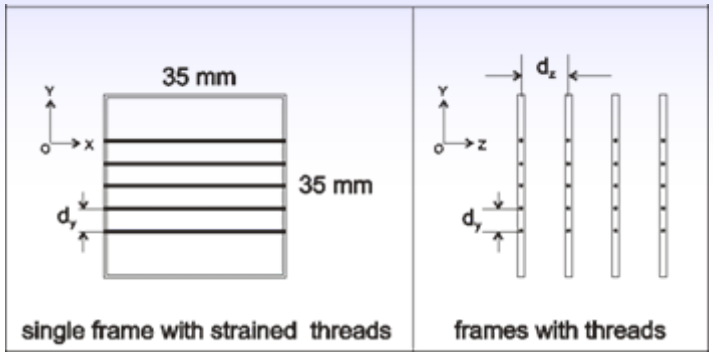
electron beam current

filtered microwave power signal 8.4 GHz

Frequency range was 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.

“Grid” VFEL with variable period: set-up

- electron beam energy about 200 keV
- pencil-like electron beam with the diameter 32 mm, electron beam current 2kA
- radiation frequency about 8.4 GHz.
- BWO regime
- resonator made of two ‘’grid’’ photonic crystals



The "grid" structure is made of separate frames each containing the layer of 5 parallel threads with the distance between the next threads d_y=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 .

Period of the second photonic crystal was 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.

“Grid” VFEL with variable period: experiment

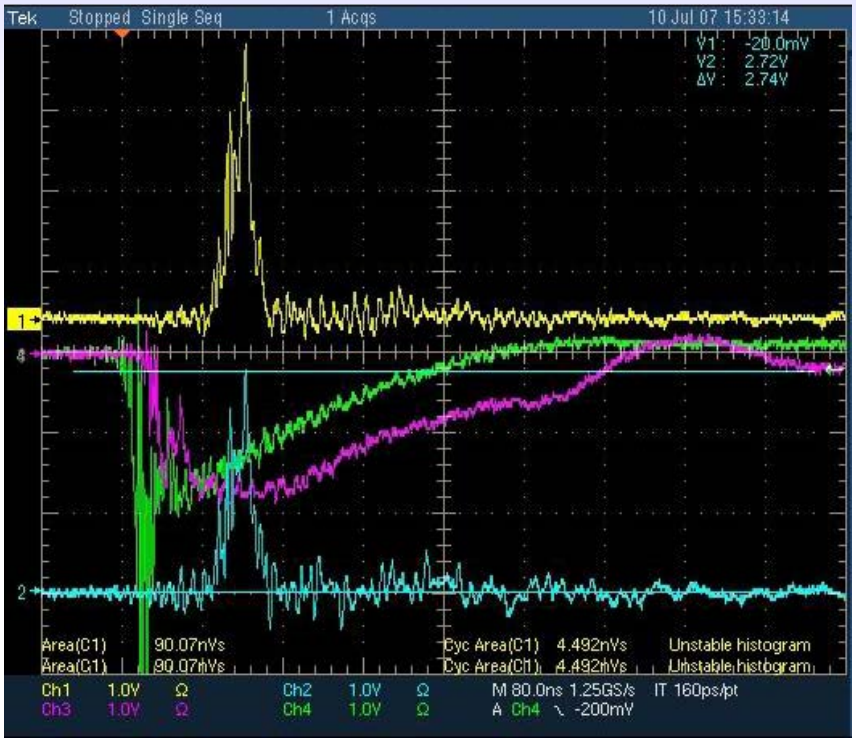
microwave power signal

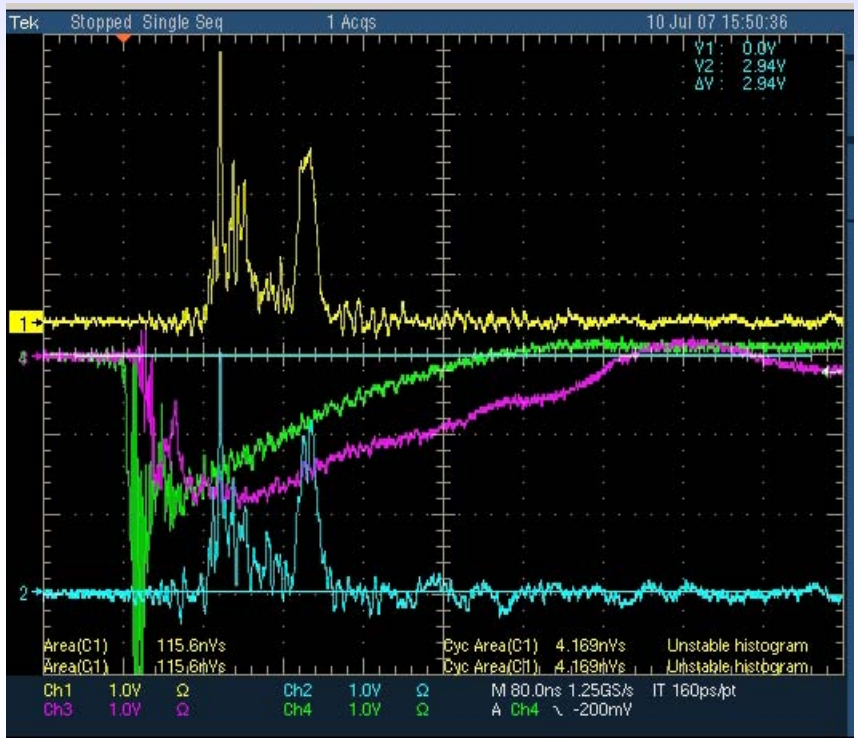
electron gun voltage

electron beam current

filtered microwave power signal 8.4 GHz

Conclusion



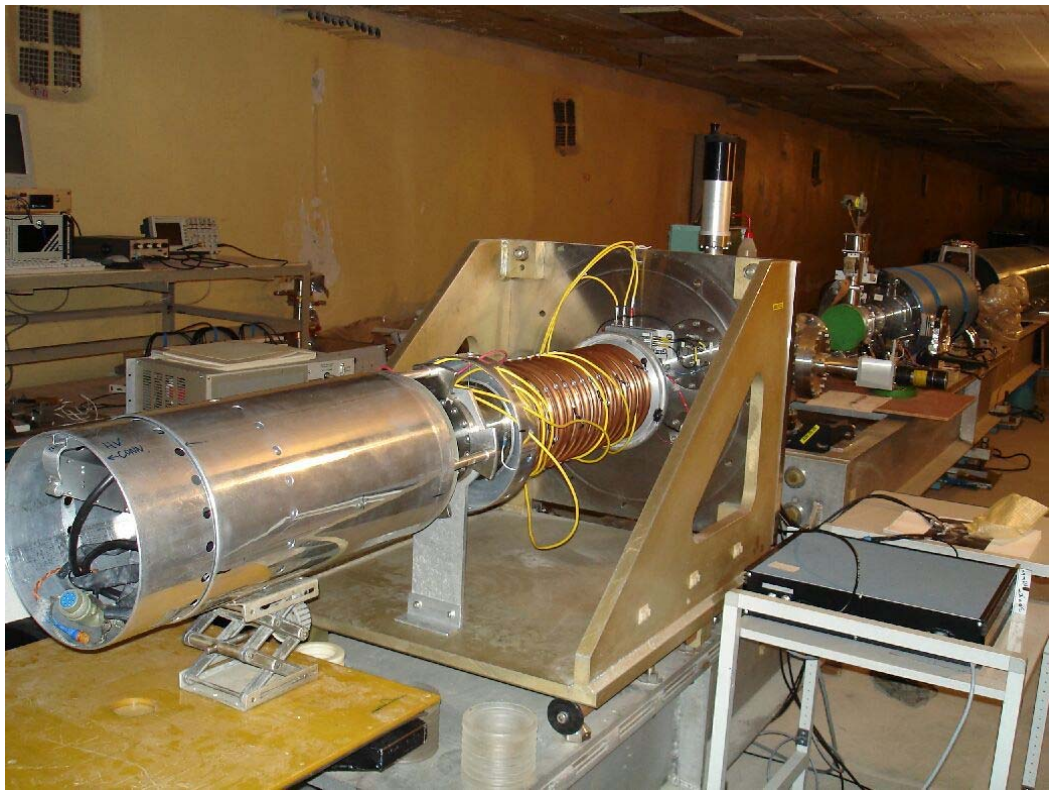


Experimental results confirmed conclusion that photonic crystal with variable period could increase radiation output.

Experiments are in progress, in particular, a photonic crystal with smoothly variable period is being prepared for experiments ….

Planned experiment with 6 MeV electrons at JINR, Dubna

Joint experiment is being prepared now by INP and Joint Institute for Nuclear Research (JINR, Dubna) at LINAC-800



6MeV electrons will be used for generation of radiation with λ= 2 mm and λ= 0.3 mm (150 GHz and 1 THz, respectively) in grid photonic crystal

Thank you for attention