Design of a photonic crystal accelerator for basic radiation biology

A. Aimidula, C.P. Welsch, *Cockcroft Institute and the University of Liverpool, UK*
G. Xia, *The University of Manchester, UK,* **K. Koyama, Y. Matsumura, M. Uesaka,** *The University of Tokyo, Japan*
T. Natsui, M. Yoshida, *High Energy Accelerator Research Organization (KEK), Japan*

Abstract

The application of photonic crystals to realize an on-chip electron beam source for fundamental radiation biology is highly interesting for a number of applications. The unique combination of nanometre beam size and attosecond-short pulses has a very promising potential for use in microscopic and ultra-fast analyses of the damage and repair of radiation-irradiated DNA and chromosomes. Simulation studies indicate an output electron beam energy, beam intensity and device size of the order of MeVs, fCs and a few cm, respectively.

Here, first results from numerical studies into the design of such compact accelerator structures are presented. The dimensions of a novel dual-grating-based acceleration structure are shown together with the estimated laser parameters. Finally, a system consisting of an electron injector and multi-stage accelerating structures is proposed, which corresponds to a miniaturized optical linear accelerator.

Acceleration Mechanism

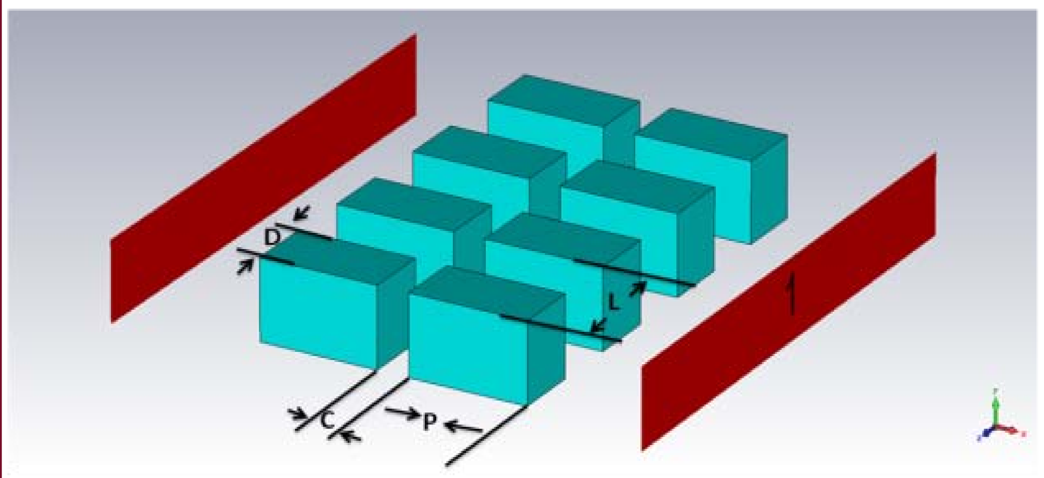
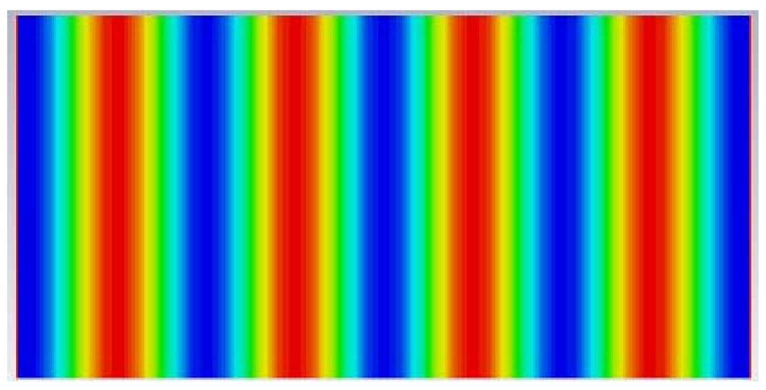
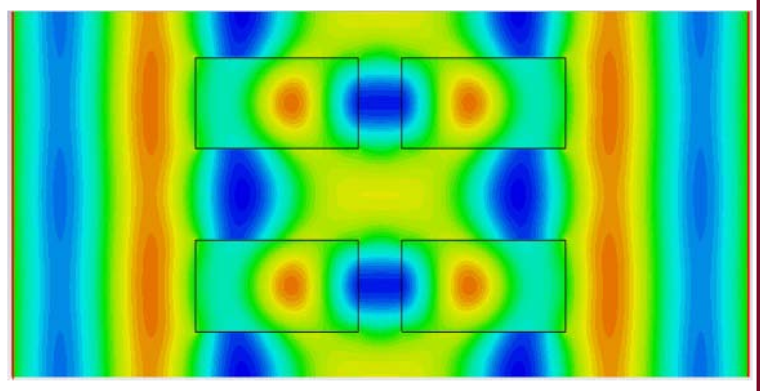


Illustration of dual-gratings structure.

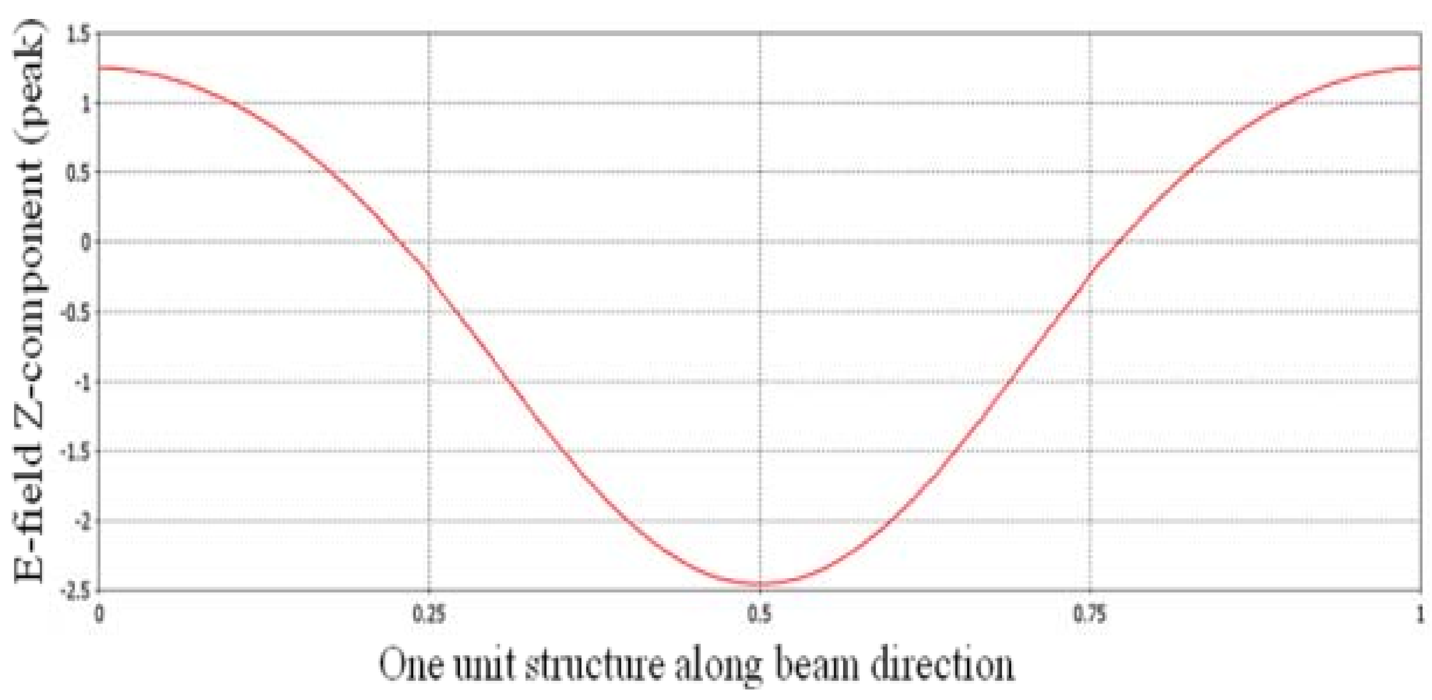
The basic working principle of dual-grating structures is based on decreasing the phase velocity of the electric field, thereby synchronizing it with non-relativistic and relativistic electrons [1].



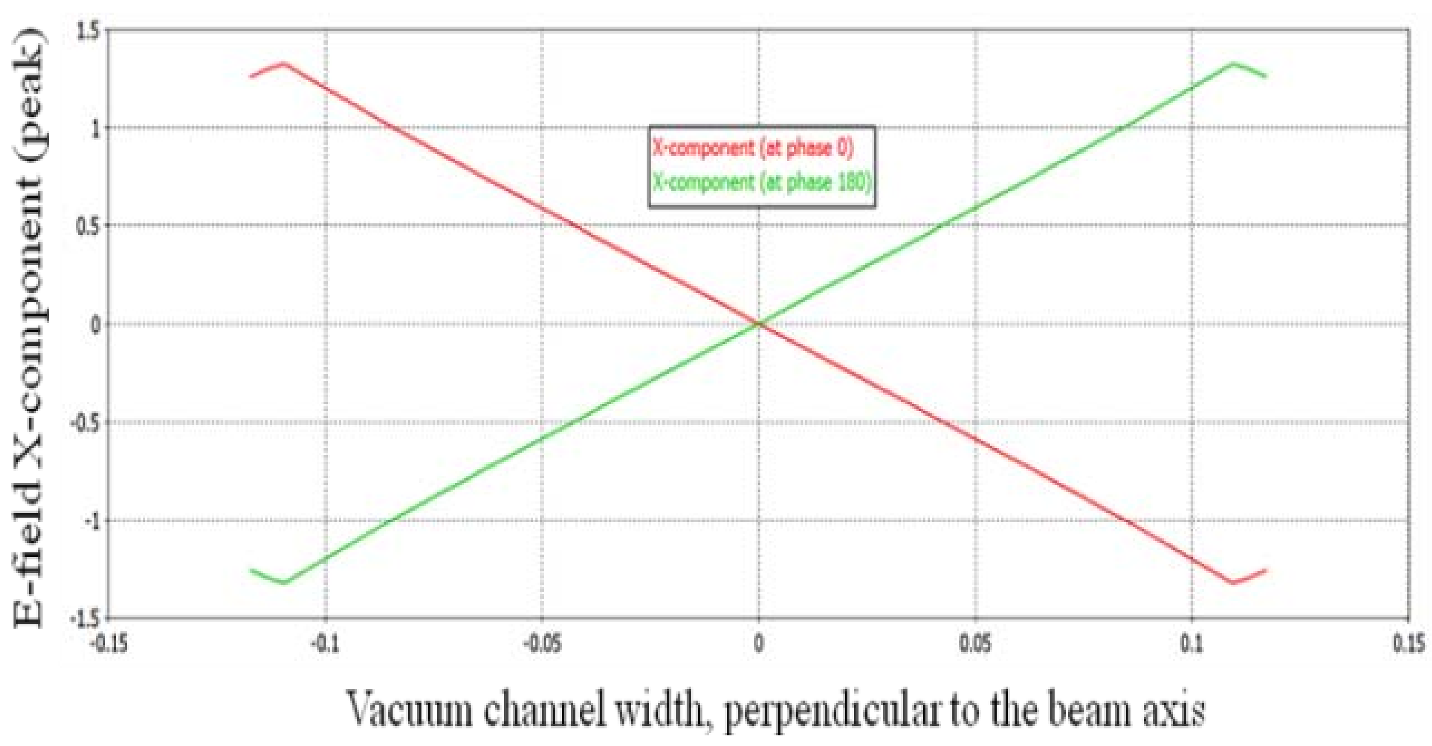
Laser field in vacuum



Simulated laser field in structure



Z-component of the electric field (peak) distribution.



x-component of the electric field (peak) distribution

References

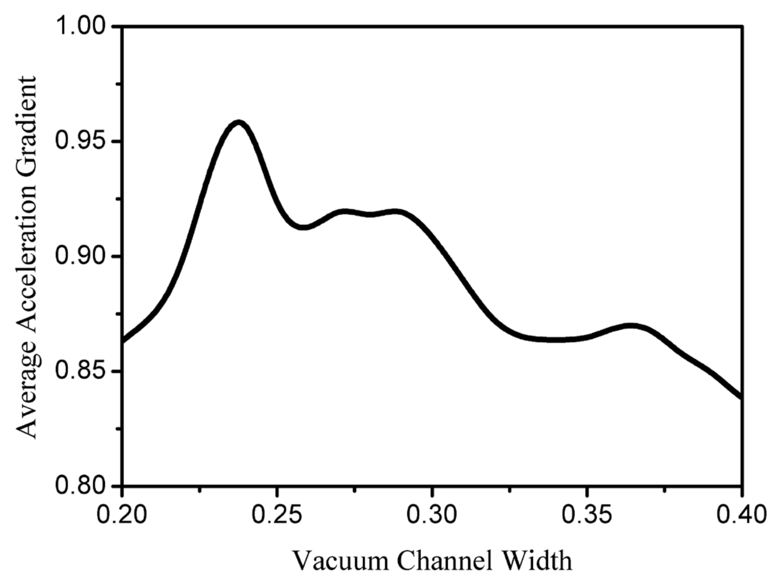
[1] T. Plettner, P. P. Lu, and R. L. Byer, Phys. Rev. ST Accel. Beams 9, 111301 (2006)

[2] B. C. Stuart, M. D. Feit, S. Herman, A. M. Rubenchik, B.W. Shore, and M. D. Perry, J. Opt. Soc. Am. B **13,** 459 (1996)

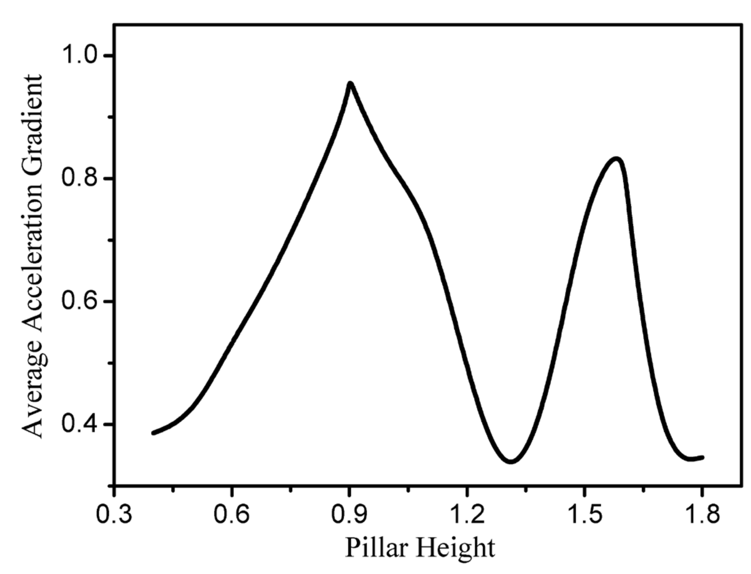
Structure Optimization

The proposed structure cross section geometry and dimensions are shown on the left. The lattice length L is λ, the dielectric length D and vacuum length are both equal to λ/2, where λ is the wavelength of the operating laser. Driving laser light is fed from the two outer surfaces, indicated in red, whilst the electrons move in the vacuum channel perpendicular to the laser traveling direction.

For the laser wavelength, we chose 1550 nm in all simulations, since many dielectric materials show high transparency at this wavelength. The final material for the accelerator structure is then chosen with respect to its transparency range, electric field damage threshold, thermal conductivity, nonlinear optical coefficients, chemical stability and refraction index. In all simulations, we selected silicon, which has an index of n=1.527.

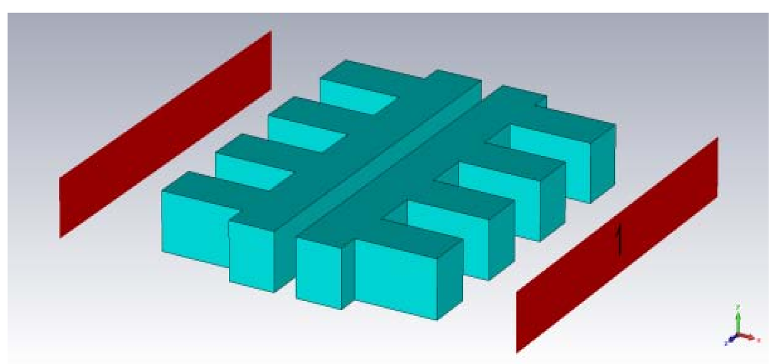


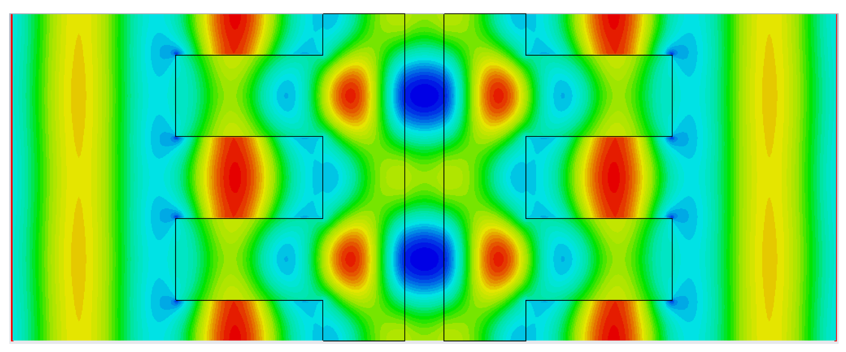
Optimum vacuum channel width



Optimum pillar height

We have determined the acceleration field gradient by particle track simulation using CST Particle Studio.





Laser requirements to get 25 MeV energy (1 cm long and 800nm wide structure):

Pulse energy: 15 μJ;
Average power: 1.5 kW;
Pulse width: 100 fs;
Repetition rate: 100 MHz.

Acceleration gradient is **3.0 GeV/m** for an unloaded field of 9.8 GV/m.

Damage threshold value is 2 J/cm^2 [2].

Future prospects and challenges

(1) Accelerate low energy electrons;
Note minimum requirement for particle beam's initial energy.

(2) Multi-stage acceleration scheme;
Design of entire structure is under investigation.

(3) Beam loading;
Focus and inject particles in hundreds-nm-wide vacuum cavity is a future challenge work.

Work supported by the EU under Grant Agreement 289191, the STFC Cockcroft Institute core grant No. ST/G008248/1, and by KAKENHI, Grant-in-Aid for Scientific Research (C) 24510120.

http://www.cockcroft.ac.uk
http://www.quasar-group.org
aimidula@liverpool.ac.uk