Comparative Analysis of Electron Acceleration by Laser Pulse in Flat and Chip Dielectric Structures

Gennadiy Sotnikov, Andrii Vasiliev, Igor Beznosenko, Sergiy Kovalov, Anatoly Povrozin, Oleh Svistunov

National Science Center "Kharkiv Institute of Physics and Technology", Kharkiv, Ukraine

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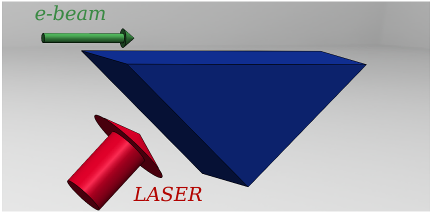
Motivation

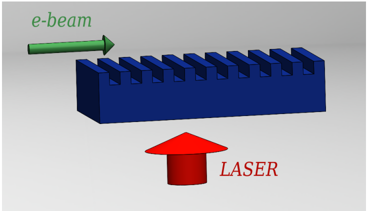
- The idea of DLA, to use dielectric structures for acceleration by waves arising from their irradiation with laser beams, arose in the last century [Kheifets, 1971; Palmer, 1980; Nagorsky, Amatuni, 1983; J.D. Lawson(1985); Khizhnyak et al, 1987; Fernow, 1991(Lohman, 1962?)]
- Interest in the use of laser beams to accelerate charged particles has renewed in the last 10 years due to the widespread use of lasers at the TW level of the micron wavelength and pulse durations 100fs [Stanford, München, UK(Cockcroft Institute in Liverpool, Manchester), Switzerland]
- Having a TW laser system, we also joined these researches. To provide the planned experiments, we began to carry out numerical calculations of the acceleration of electron beams using dielectric structures.

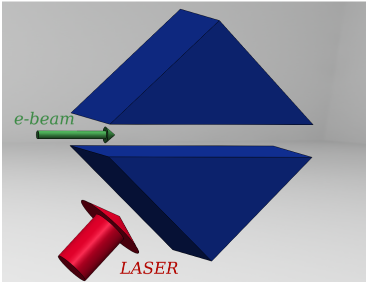
Motivation

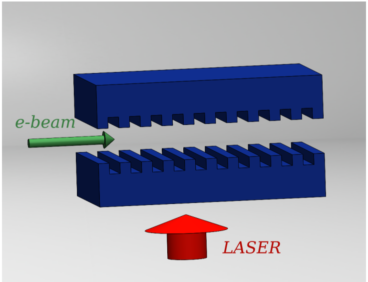
- Two types of dielectric structures are mainly used for electron acceleration in DLA - flat and periodic chip (or grating) structures
- DLA with flat structure is smooth surface irradiated by laser pulse under an angle of the full internal reflection – so called inverse Cherenkov DLA
- DLA with Chip structure is periodic structure irradiated laser pulse usually under right angle – so called inverse Smith-Purcell DLA
- Comparative analysis of these types DLA's is absent. Here we will present the simulation results of electron beam acceleration in Flat and Chip structures for different initial energies of them, find acceleration rates and compare them.

Schematic view of structures









$$E_x(r,z,t) =$$
$$E_L \frac{w_0}{w(z)} \exp(-\frac{w_0^2}{w^2(z)}) \exp(-2\ln(2)\frac{(z-ct)^2}{c^2\tau_0^2})\mathfrak{R}\{\exp[i\omega_0 t - ik_0 z - ik_0\frac{r^2}{2R(z)} + i\psi_g(z)]\}$$

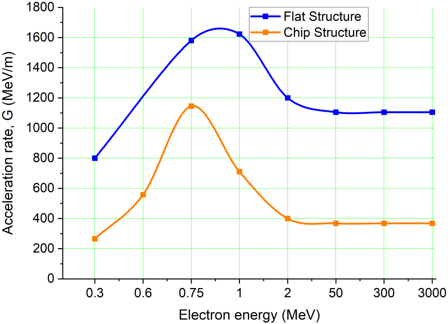
Parameters of laser pulse and electron beam for PIC simualtion

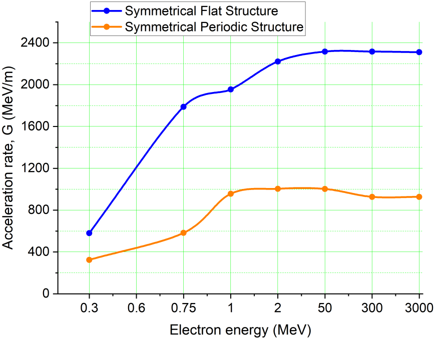
Item	Value	Units
Central wavelength of pulse λ_L	800	nm
Laser spectrum width	20	nm
Laser pulse waist w_0	20	μm
Wave amplitude E_L	$6 \cdot 10^9$	V/m
RMS duration of Laser pulse τ_0	120	fs
Dielectric permittivity of structure ε	2.112	fused silica
Period of chip structure $L_s = \beta_0 \lambda_L$	≤ 800	nm
Pillar height and width of chip structure	400	nm
Angle of the full internal reflection ϑ	43.48	degree
Electron beam energy W_b	$0.3 \div 3000$	MeV
Electron beam transverse size	50	nm
Vertical distance of beam from surface	200	nm
Vacuum gap for symmetrical case	400	nm
Electron beam duration τ_b	5.4	fs

Acceleration rate: final results

Left: *single structure,* *Right:* *double (symmetrical) structure*

Acceleration rates are computed using maximal accelerated electrons

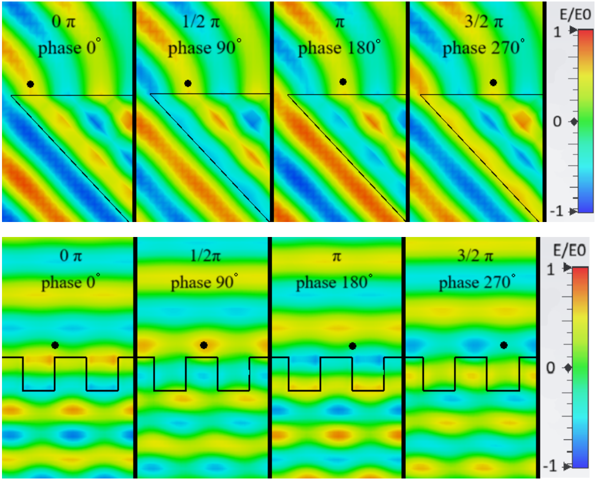




Note the acceleration rate don't depend from beam energy for ultra-relativistic electrons (???) both for single and double DLA.

Why is difference in DLA acceleration on Flat and Chip structures?

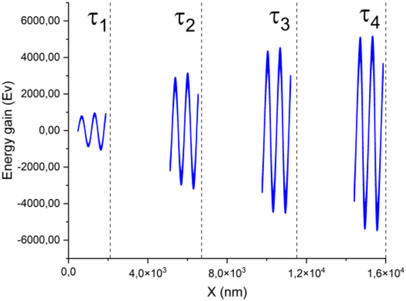
Maps of accelerated field distribution acting on electron

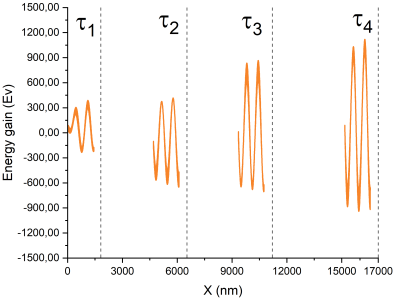


Top: flat(single) structure, Bottom chip(single) structure:

Energy gain of electron beams

Left: *flat(single) structure,* *Right:* *chip(single) structure*

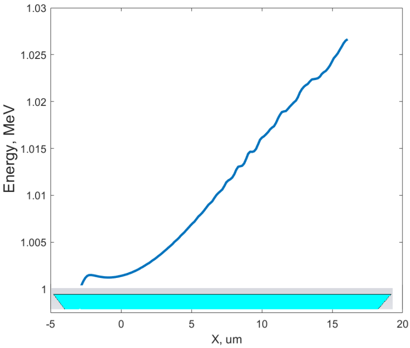


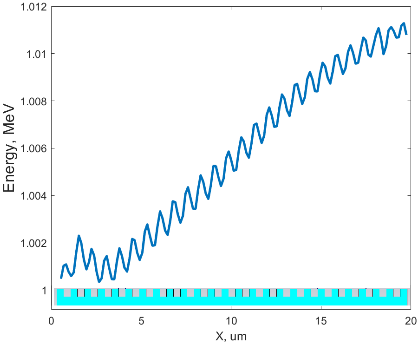


Beam length $L_b = 2\lambda_L$, $W_b = 300\ keV$

Average energy gain of short electron beams

Left: *flat(single) structure*, *Right:* *chip(single) structure*





Beam length $L_b = 120nm \ll \lambda_L$, $W_b = 1\,MeV$

Conclusion

1. Flat dielectric structure provides more effective acceleration in a wide range of energies, especially with a symmetrical geometry (double structures), compared with the periodic structure.

2. The periodic structure with symmetric geometry has an acceleration rate twice that of the single configuration.

3. The use periodic structure with one-sided configuration turns out to be preferable for accelerating electrons with moderate energies, < 1 MeV, where the acceleration rate is higher than in a symmetric (double) configuration.

Thank you for your attention!