Geometric optimization study for a Dielectric Laser Accelerator

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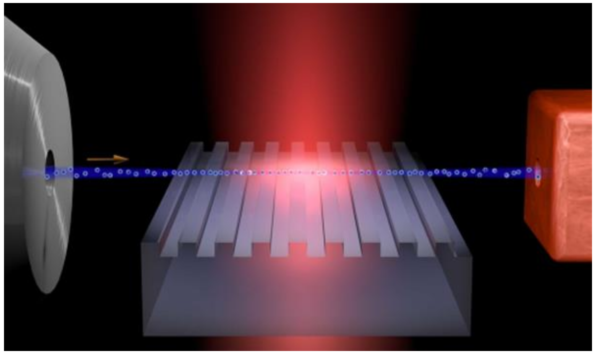
Outline

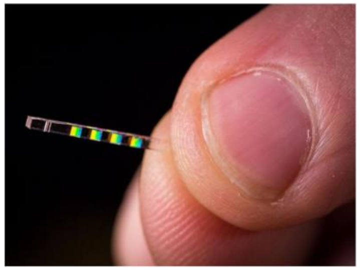
- Motivation
- Simulation study for geometry optimization
  - Synchronicity condition
  - Cylindrical and cuboid dual grating structures
  - PIC simulations of non relativistic and relativistic electron beams
- Conclusions from the comparative studies
- Future goals

Motivation

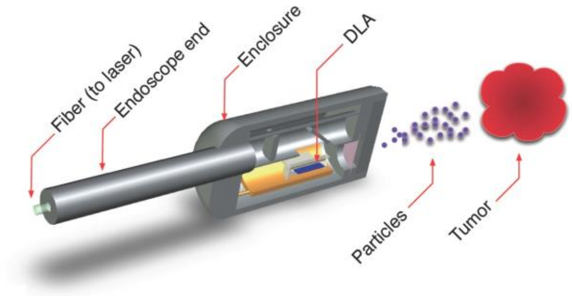
DLAs are potential candidate for acceleration gradient in the GV/m regime from the grating-shaped dielectric microstructures and can have applications in cancer treatment.



J. Breuer/MPI



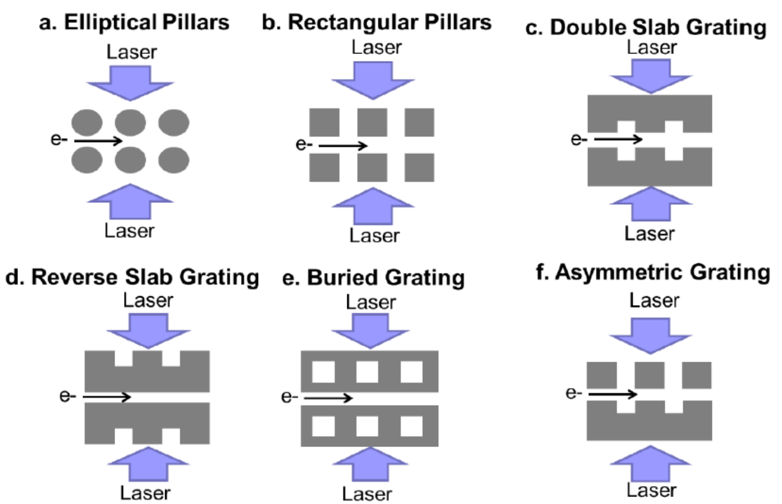
SLAC



Gil Travish, UCLA

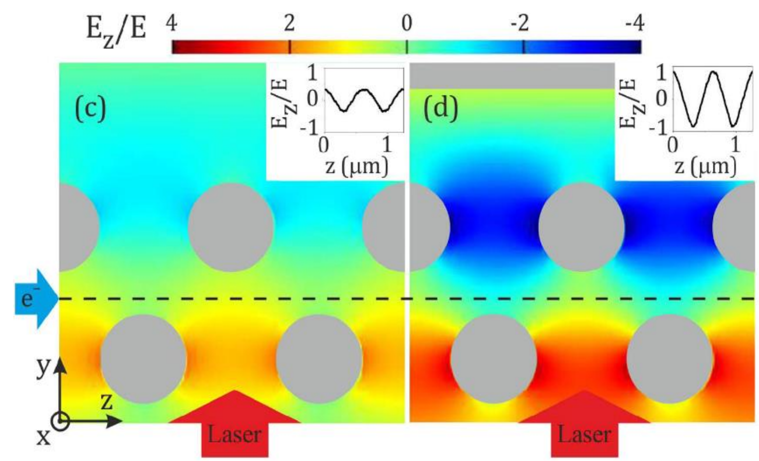
R. Joel England, “Dielectric laser accelerators”, Rev. Mod. Phys., 86:1337–1389, Dec 2014

Motivation



(a) K. J. Leedle, *et al.*, (b) A. Aimidula, *et al*, (c) T. Plettner, *et al*, (d) A. Aimidula, *et al*, (e) C.-M. Chang *et al*, (f) any combination

K.P. Wooton, SLAC-PUB-16810



Peyman Yousefi *et al*, with distributed Bragg reflectors

Simulation study for geometry optimization

- **Simulation Code**: CST Studio suite

Solvers:

Time domain for Electric field

Particle in Cell for charge particle dynamics

Synchronicity condition

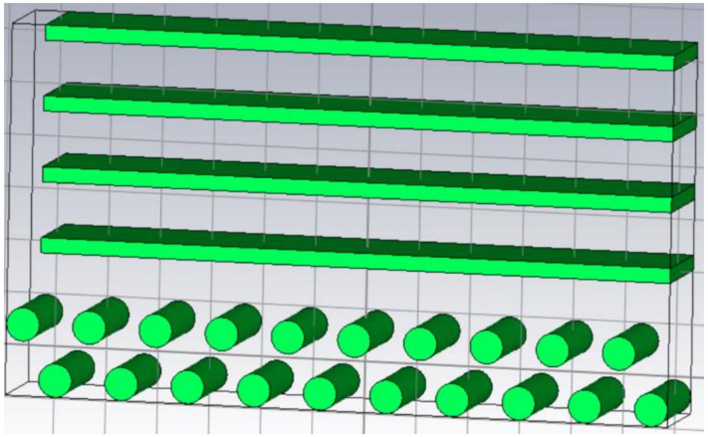
$$mk_g + k/(\beta \cos \alpha) = 0$$

m = order of harmonic, k_g = wavevector related to grating period, k = wavevector of incident EM wave, β = Lorentz factor and α = grating tilt angle.

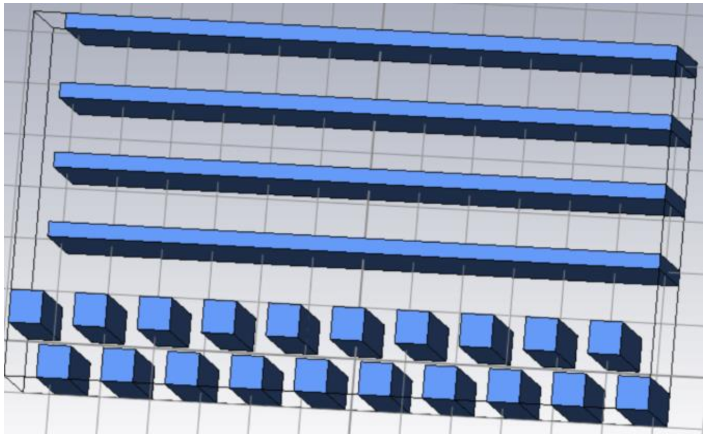
E. Peralta . Accelerator on a chip: Design, fabrication, and demonstration….. Thesis (Ph.D.)–Stanford University, 2015.

Two different shapes, but with same grating parameters

(a)



(b)



(a) Cylindrical and (b) cuboid shaped dielectric structures. It’s a dual pillar with 4 Bragg reflectors.

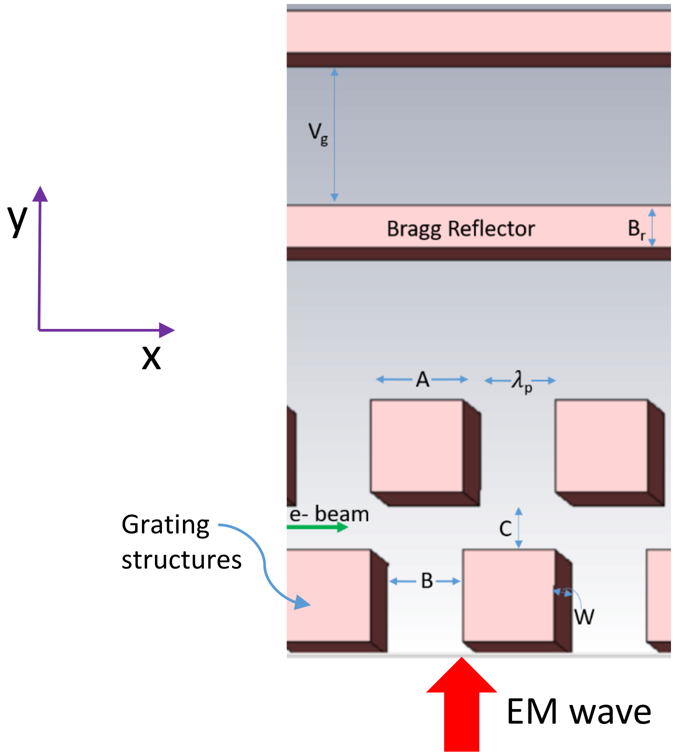
Peyman Yousefi *et al*, “Dielectric laser electron acceleration in a dual pillar grating with a distributed Bragg reflector”, Opt. Lett. 44, 1520-1523 (2019)
Y. Wei *et a*l, “Dual-gratings with a Bragg reflector for dielectric laser-driven accelerators”, Physics of Plasmas 24, 073115 (2017)

Parameters for non relativistic case

Electron beam initial energy = 28.4 keV, $\beta \approx 0.3$

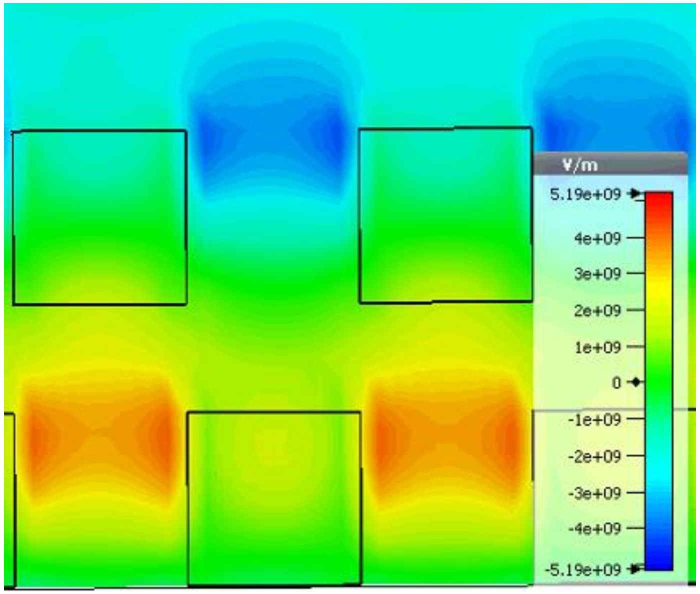
Laser wavelength = 2000 nm, pulse duration = 100 fs, electric field amplitude = 1.5 GV/m, material = silicon

Parameter	Value (in nm)
A	320
B	320
C	200
W	1000
B_r	145
V_g	250
λp	640

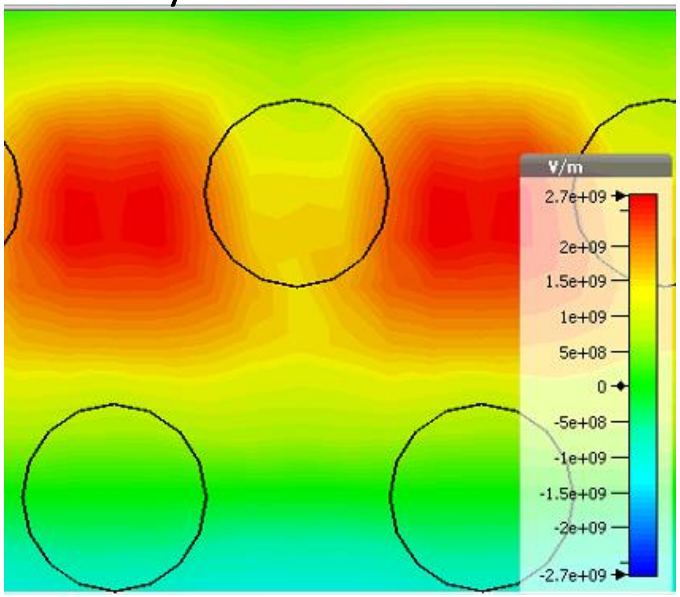


Electric field distribution

Cuboid



Cylindrical

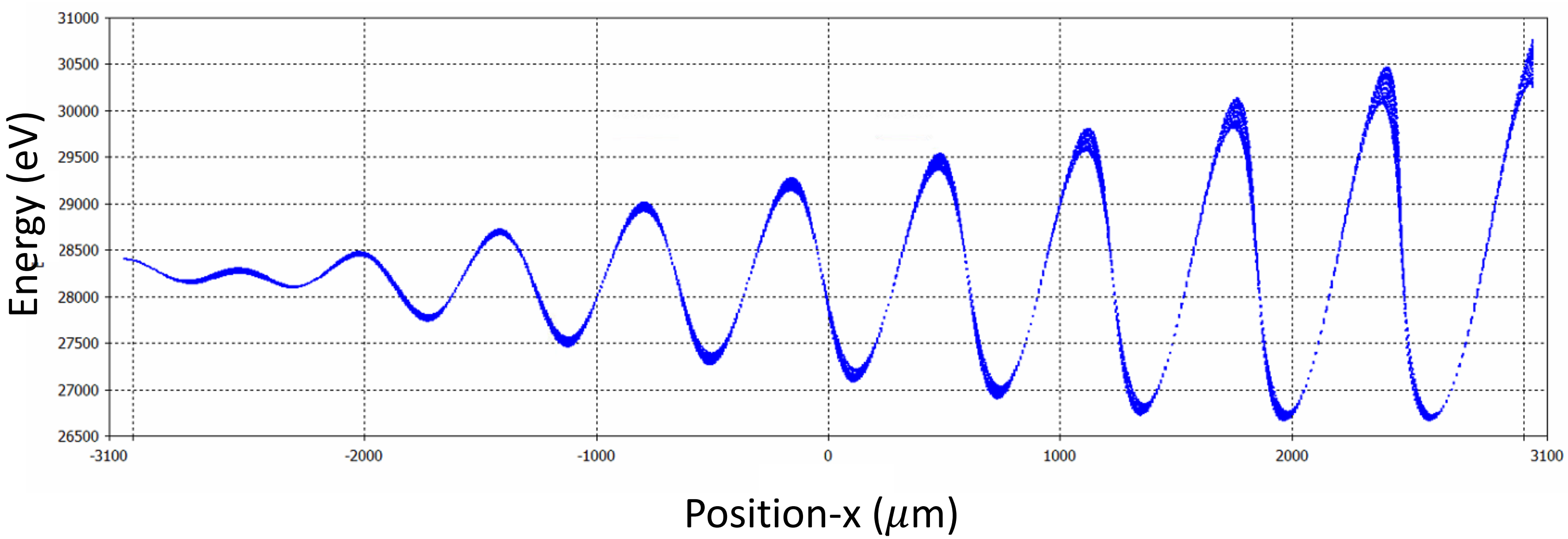


Maximum field obtained = 5.19 GV/m

Maximum field obtained = 2.7 GV/m

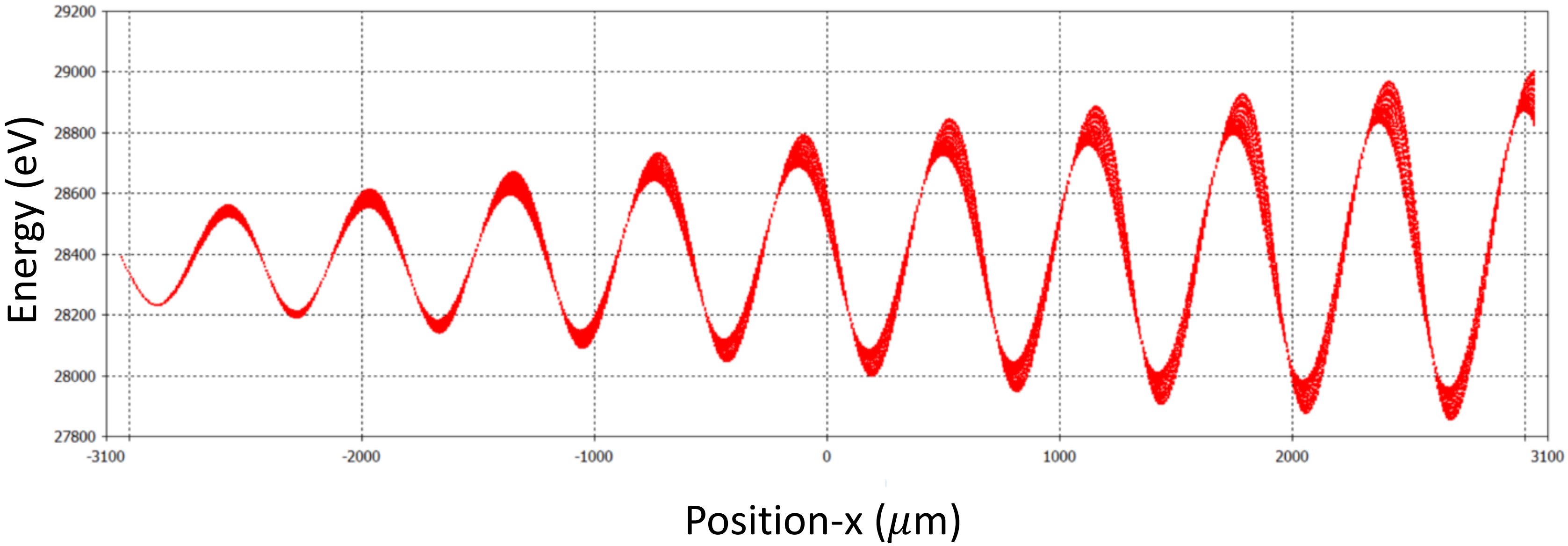
2-D cut of the electric field amplitude distribution. Upper pillars are shifted by one grating period to achieve higher field amplitude

Energy gain (cuboid structures)



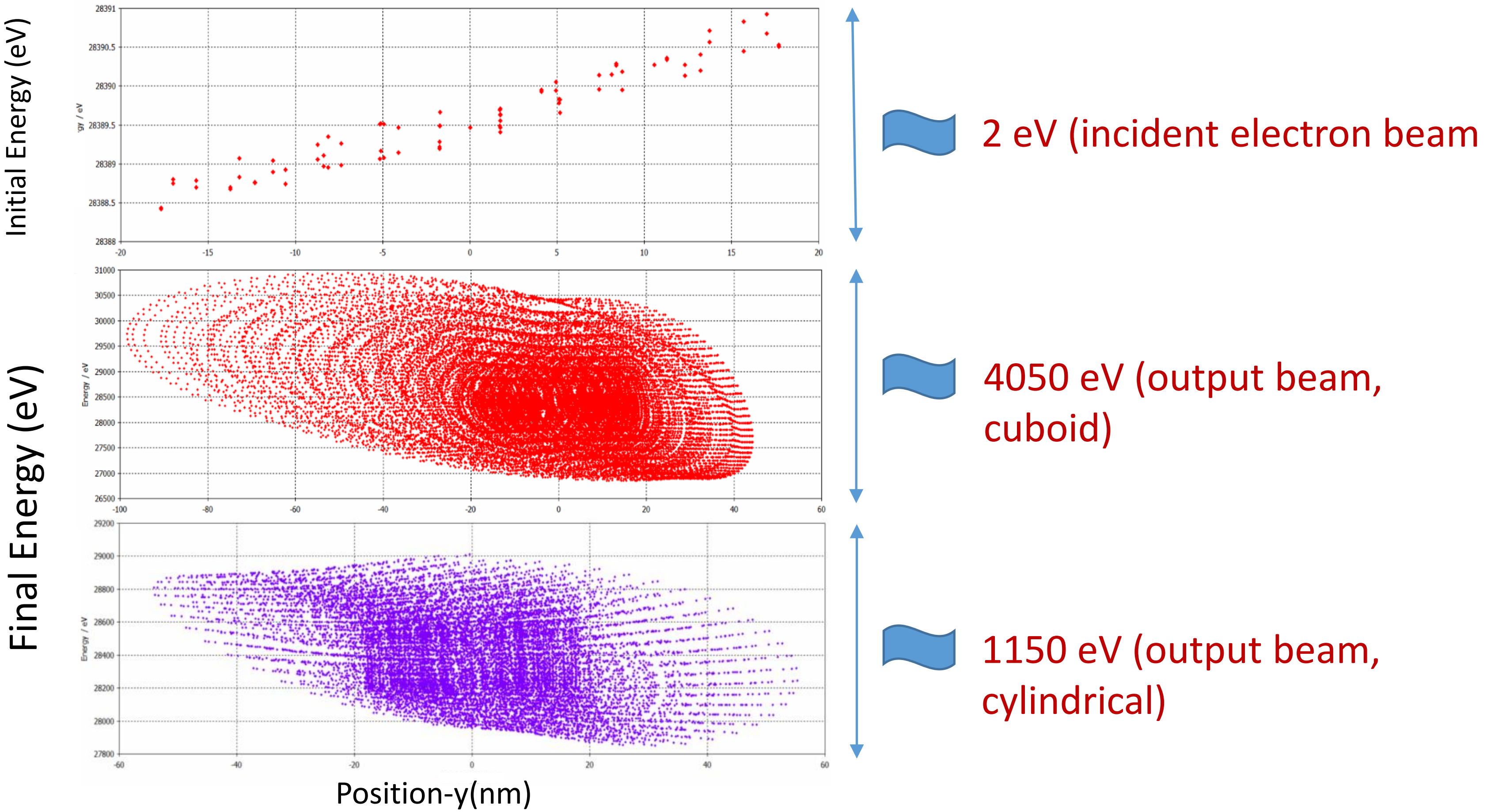
Energy gain = 2500 eV, Acceleration gradient = 416 MeV/m, Particles = 77598

Energy gain (cylindrical structures)



Energy gain = 600 eV, Acceleration gradient = 97 MeV/m, Particles = 33680

Energy spread

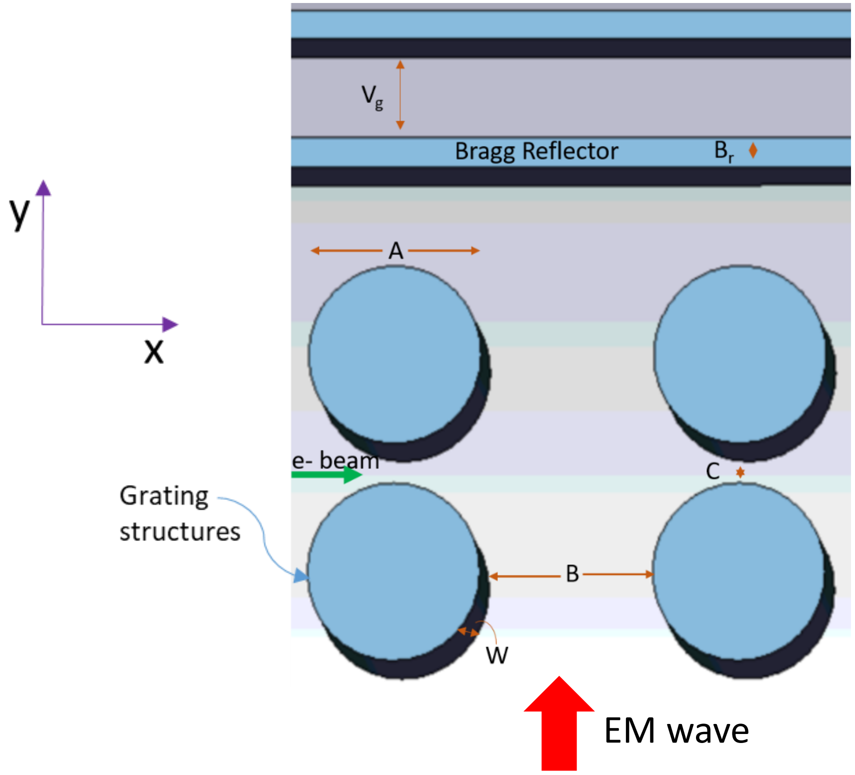


Parameters for Relativistic case

Electron beam initial energy = 1 MeV, $\beta \approx 0.94$

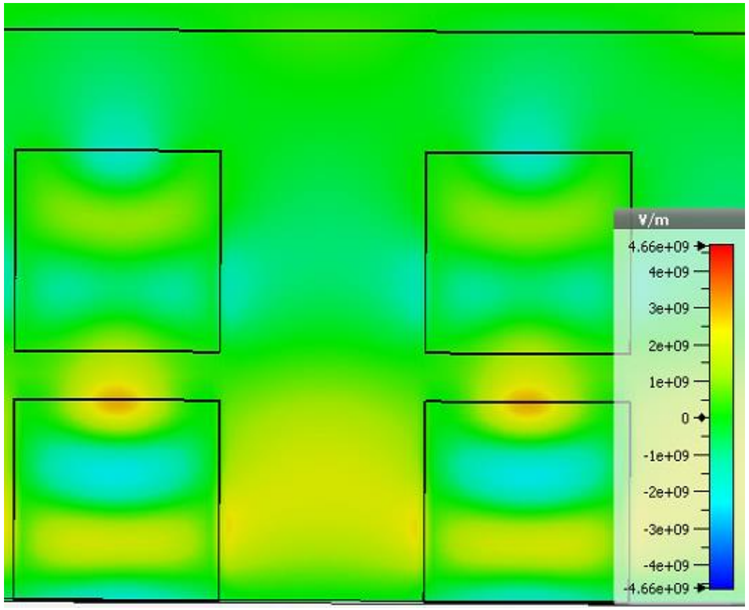
Laser wavelength = 2000 nm, pulse duration = 100 fs, electric field amplitude = 1.5 GV/m, material = silicon

Parameter	Value (in nm)
A	900
B	900
C	200
W	1000
B_r	147
V_g	500
λp	0



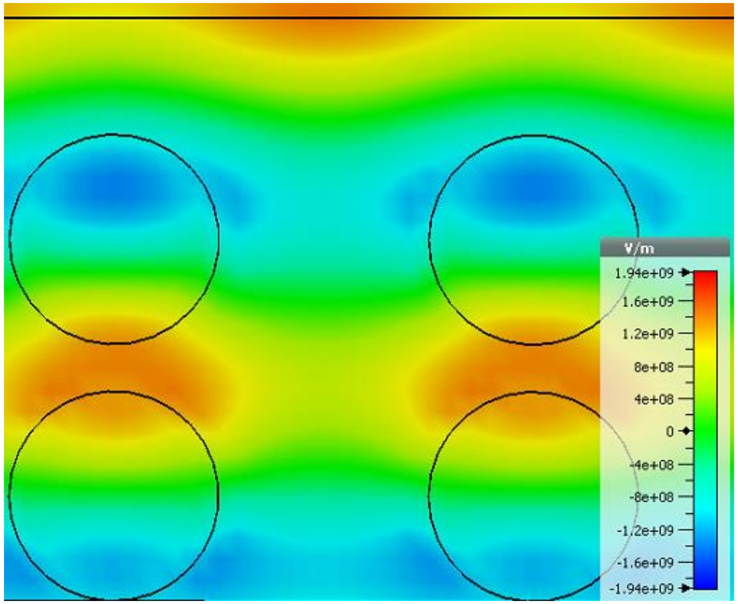
Electric field distribution

Cuboid



Maximum field obtained = 4.66 GV/m

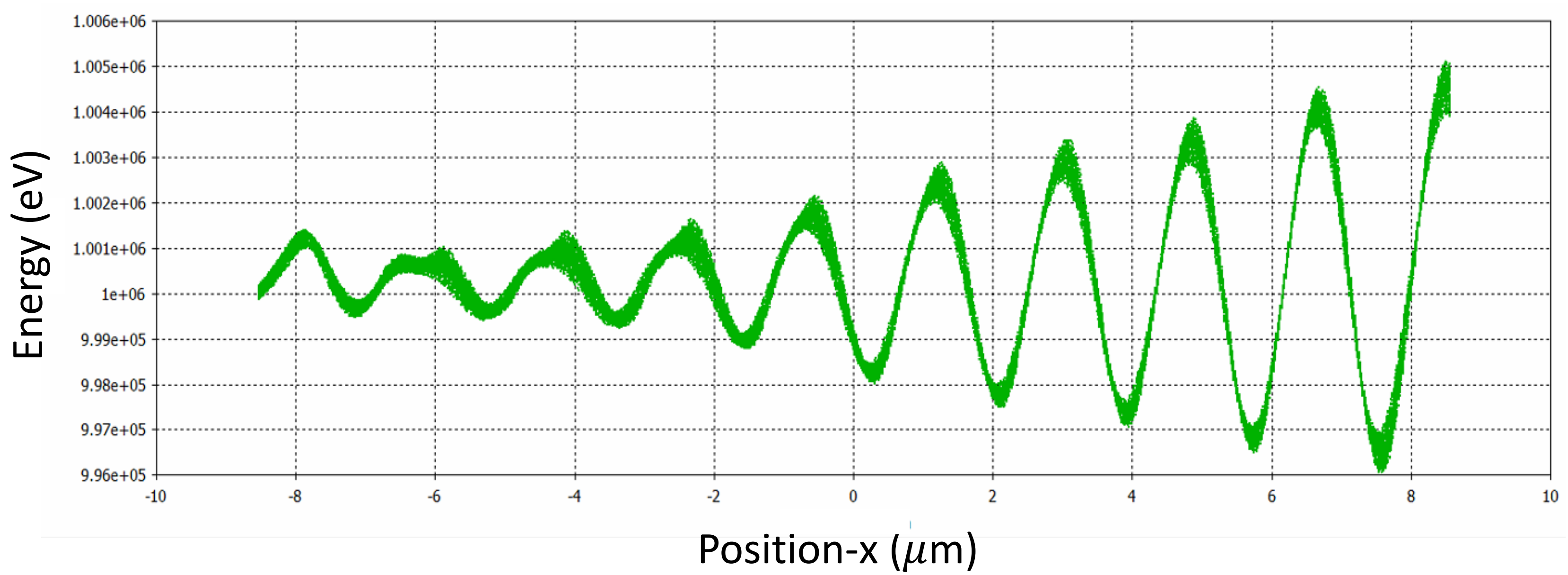
Cylindrical



Maximum field obtained = 2.91 GV/m

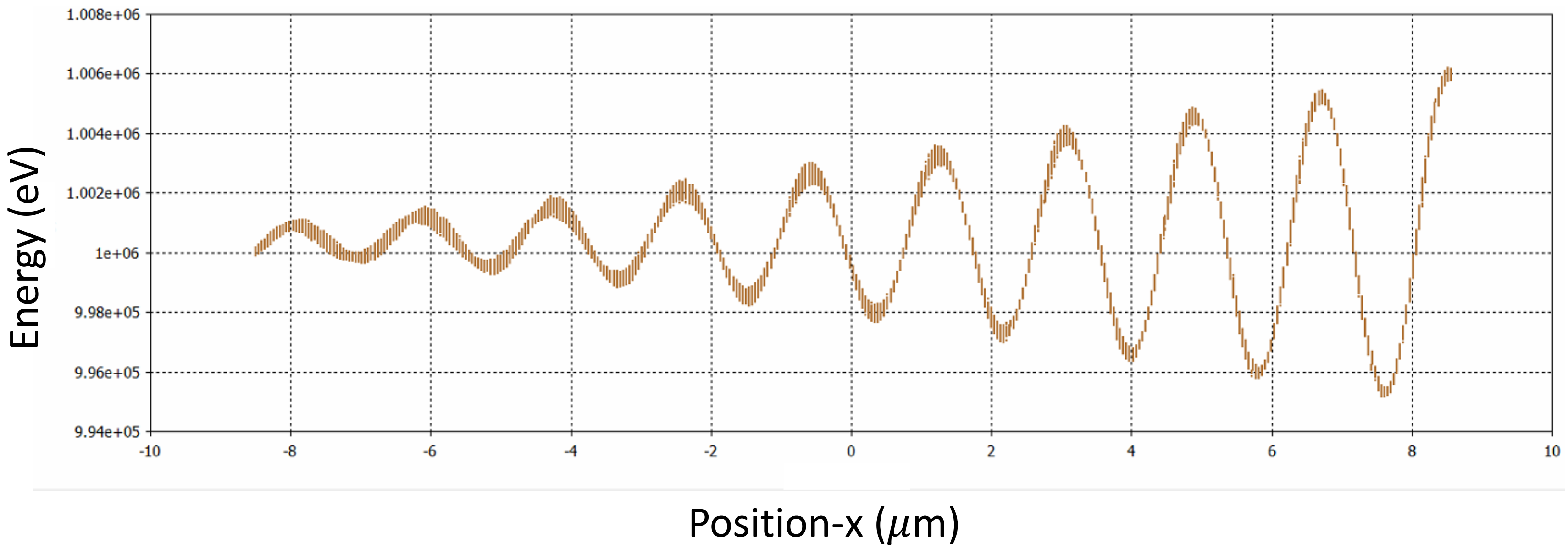
2-D cut of the electric field amplitude distribution.

Energy gain (cuboid structures)



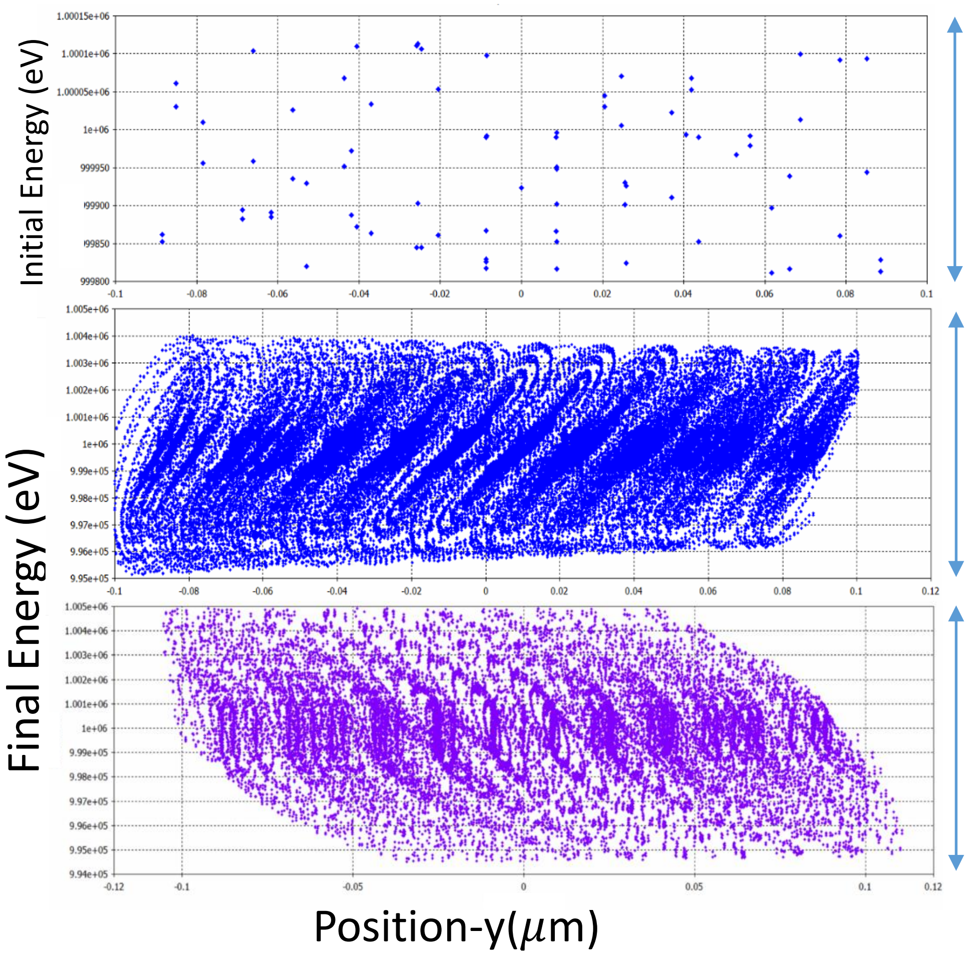
Energy gain = 5 keV, Acceleration gradient = 308 MeV/m, Particles = 72479

Energy gain (cylindrical structures)



Energy gain = 6 keV, Acceleration gradient = 370 MeV/m, Particles = 30151

Energy spread



0.03 MeV (incident electron beam)

0.009 MeV (output beam, cuboid)

0.01 MeV (output beam, cylindrical)

Conclusion of the comparative study

	Non-Relativistic	Relativistic
Energy gain	Cuboid > Cylindrical	Cuboid < Cylindrical
Acceleration gradient	Cuboid > Cylindrical	Cuboid < Cylindrical
Energy spread	Cuboid > Cylindrical	Cuboid < Cylindrical
No. of particles	Cuboid > Cylindrical	Cuboid > Cylindrical

Future directions

- Algorithmic approach for the determination of most suitable shapes.
- Analyse and compare the difficulties and precision in the manufacturing of various structures.
- Experiments.

Acknowledgement

I thank my supervisors for their kind support and guidance throughout this period. I acknowledge Dr. Guoxing Xia for his discussions about this research and Dr. Yelong Wei for handling my questions entrancingly.

Thank You!

Questions?