Influence of the Profile of the Dielectric Structure on the Electric Fields Excited by a Laser in Dielectric Accelerators Based on Chip

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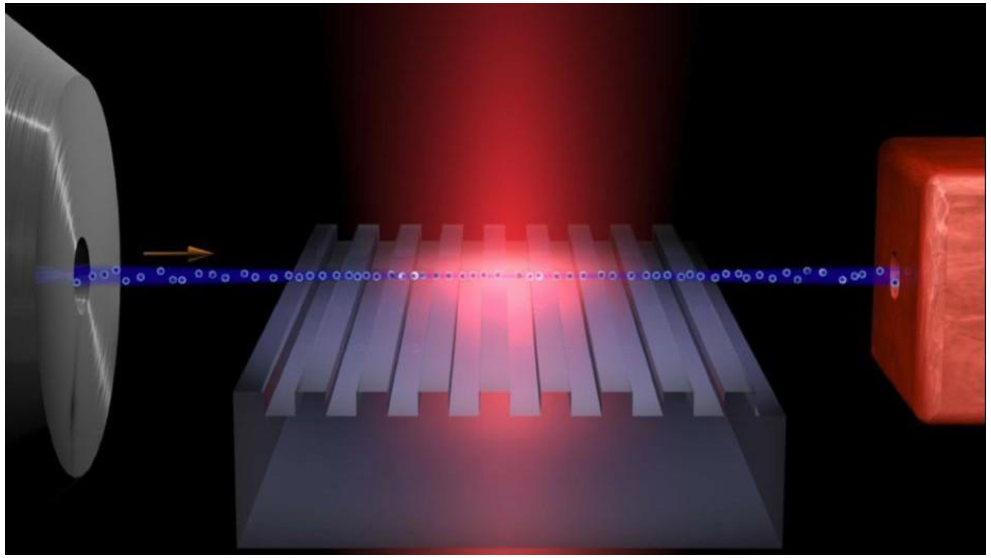
2021

Relevance

For accelerators based on CHIP structures, two directions are relevant. With the maximum miniaturization of devices - obtaining the maximum efficiency of acceleration and on this basis - their optimization for the production of this type of accelerators for consumer and research purposes.

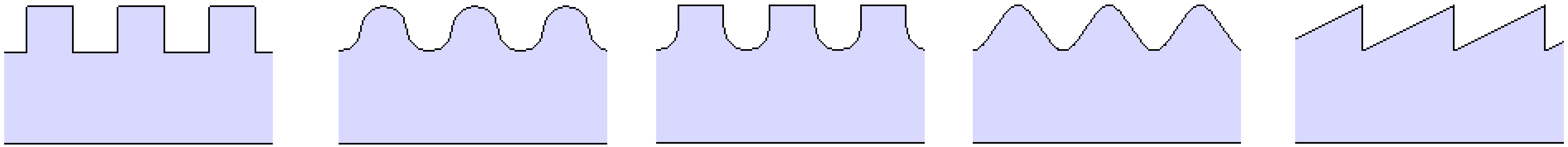


Chip-structure damage threshold	30 GV/m
Max. achievable gradient	10 GeV/m
Drive period	~ 5 fs

Fields of promising application: medicine, materials science, biochemistry, in physics - obtaining ultrashort electron bunches of the order of 5-10 fs.

Modeling subject

Experiments were carried out to simulate acceleration processes on periodic structures of various profiles



1 – Rectangular, 2 – Cylindrical, 3 – Grooves, 4 – Sinusoidal, 5 – Triangular

Structure period λ_p = 800 nm; Pillar height $h=\lambda_p/2$; Structure length L=16 μm

1) when they are excited by a plane wave -

$$\tilde{E}_p = E_p \exp\left[-\left(\frac{x}{w_1}\right)^2 - 2\ln(2)\left(\frac{t}{\tau_p}\right)^2\right]$$

2) and Gaussian wave –

$$E(r,z,t) = E_p \frac{w_0}{w(z)} \exp\left[-\frac{r^2}{w^2(z)}\right] \exp\left[-2\ln(2)\frac{(z-ct)^2}{c^2\tau_0^2}\right]$$

$$\times \Re\left\{\exp\left[i\omega_0 t - ik_0 z - ik_0 \frac{r^2}{2R(z)} + i\psi_g(z)\right]\right\}$$

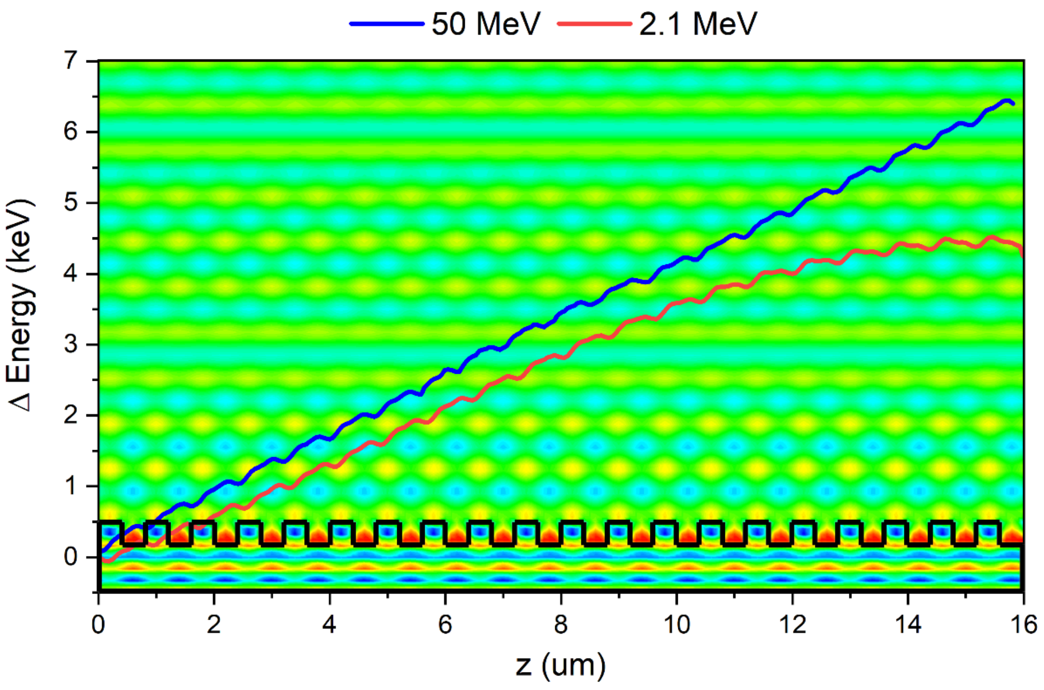
Where E_p - electric field amplitude, w_0 - laser waist at z = 0, τ_0 - laser pulse duration, c - speed of light, $k_0 = 2\pi / \lambda_0$ and $\omega_0 = ck_0$ – wave number and angular frequency of a laser beam with a wavelength λ_0, $w(z)$ – beam waist on the z axis, $R(z)$ – the radius of curvature of the wave front, $\psi_g(z)$ – Phase Shift Gouy

Average energy gain for a rectangular structure

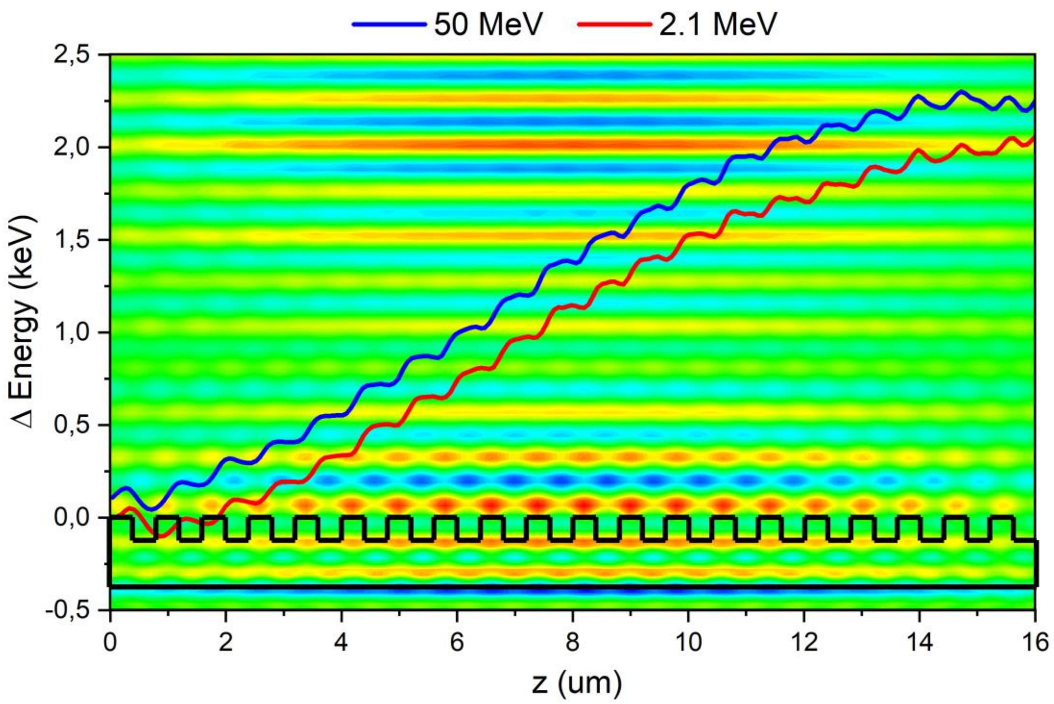
The height of the flight of electron beam over the structure $y = 200$ nm,

$E_p = 10^9$ V/m

Plane wave



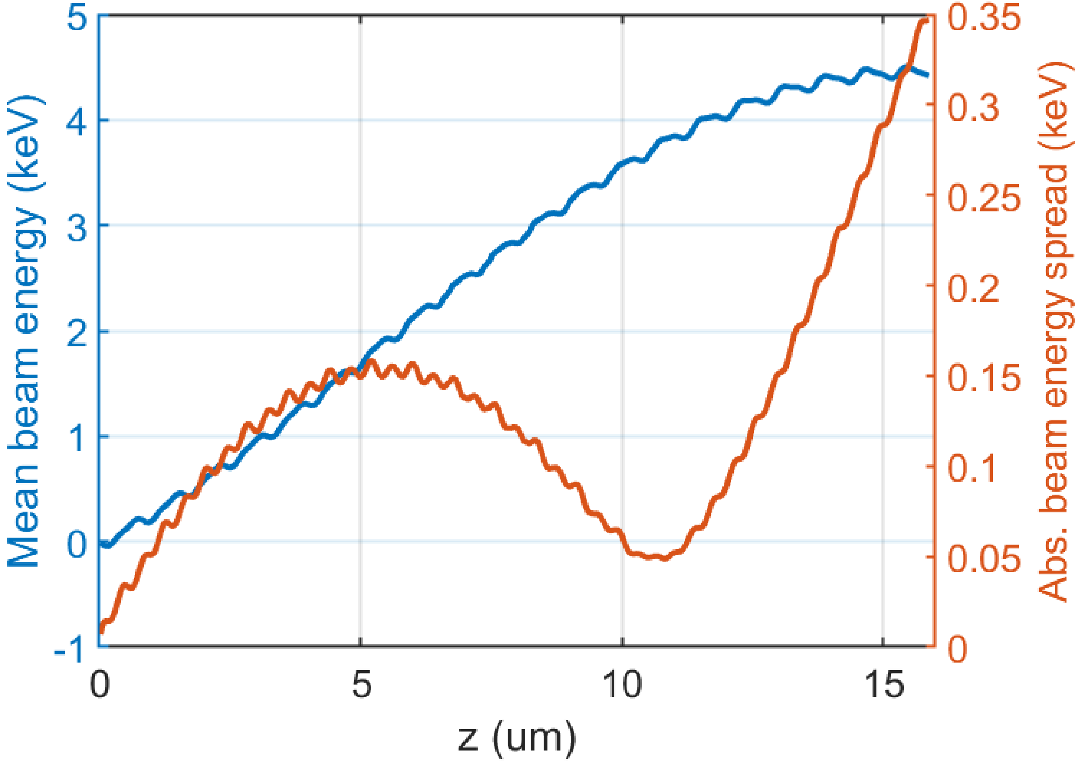
Gauss wave



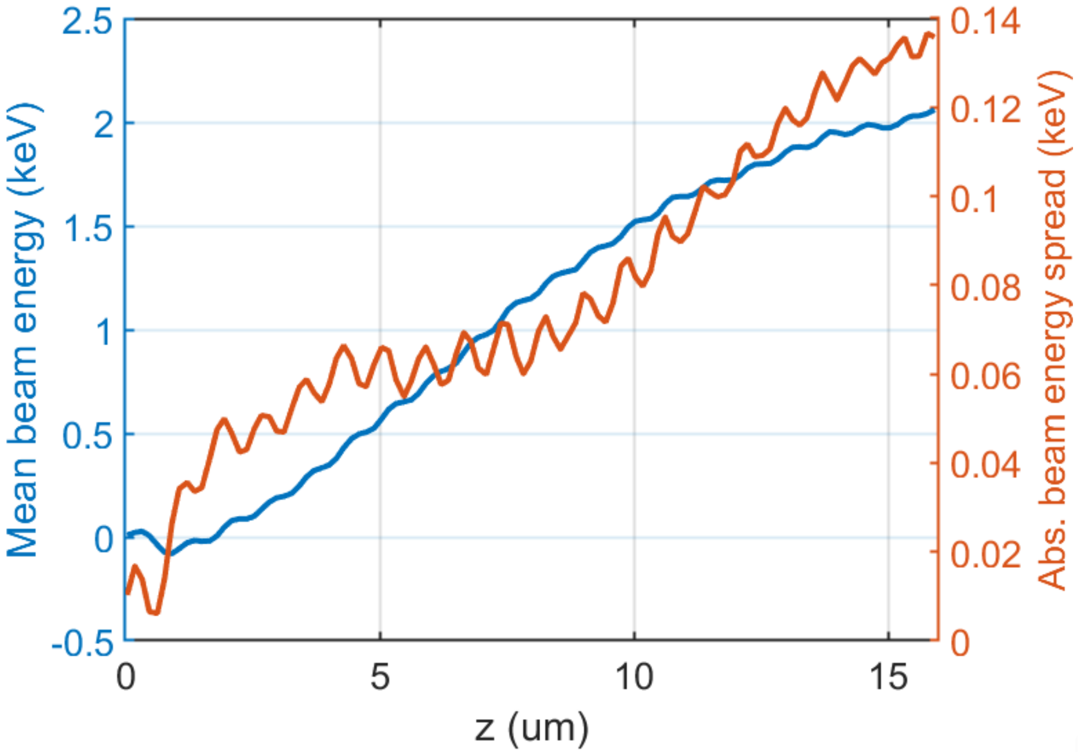
Average gain and spread of electron energy for a rectangular structure

$y = 200$ nm, $E_p = 10^9$ V/m, $E_0 = 2.1$ MeV

Plane wave

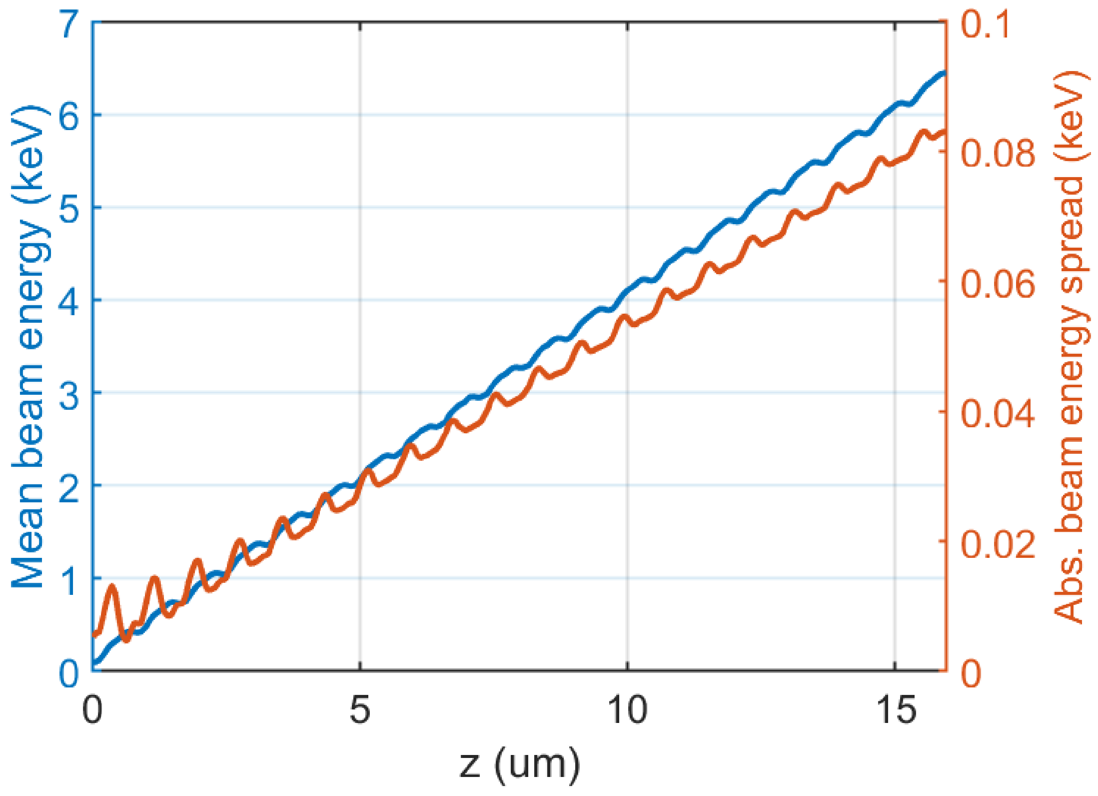


Gauss wave

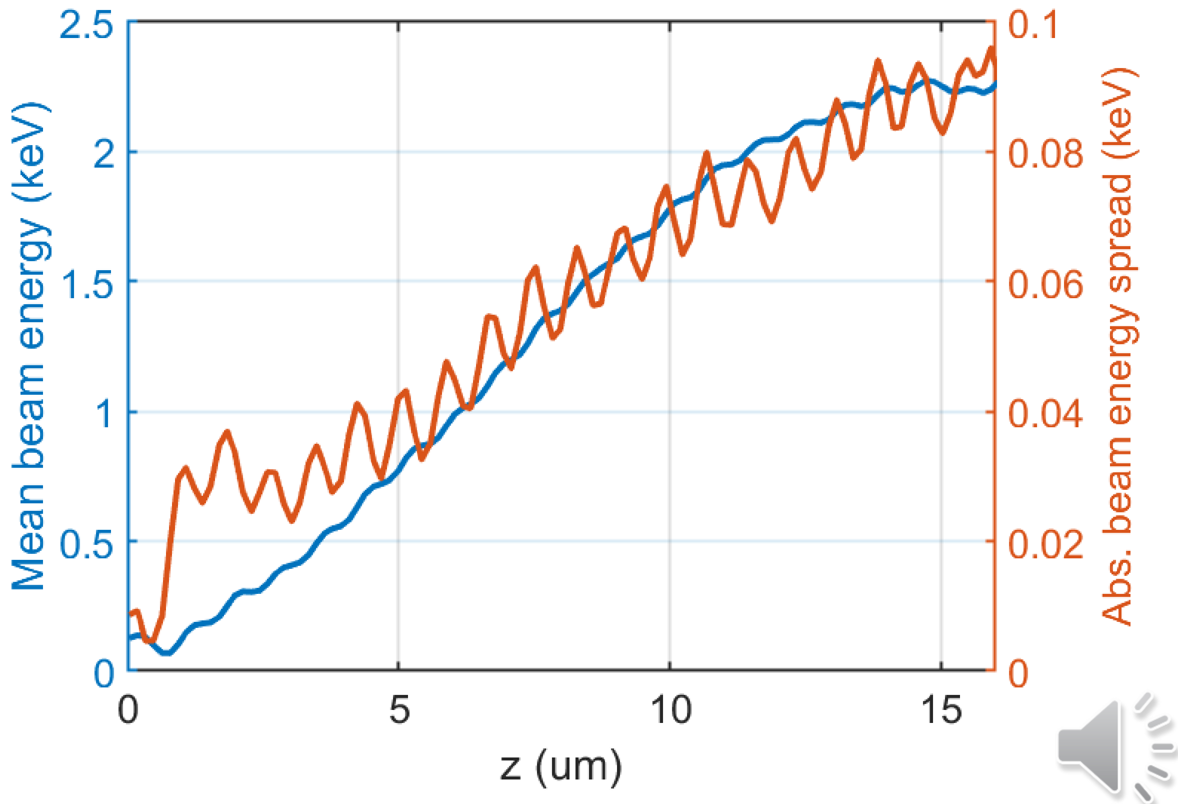


Average gain and spread of electron energy for a rectangular structure
$y = 200$ nm, $E_p = 10^9$ V/m, $E_0 = 50$ MeV

Plane wave



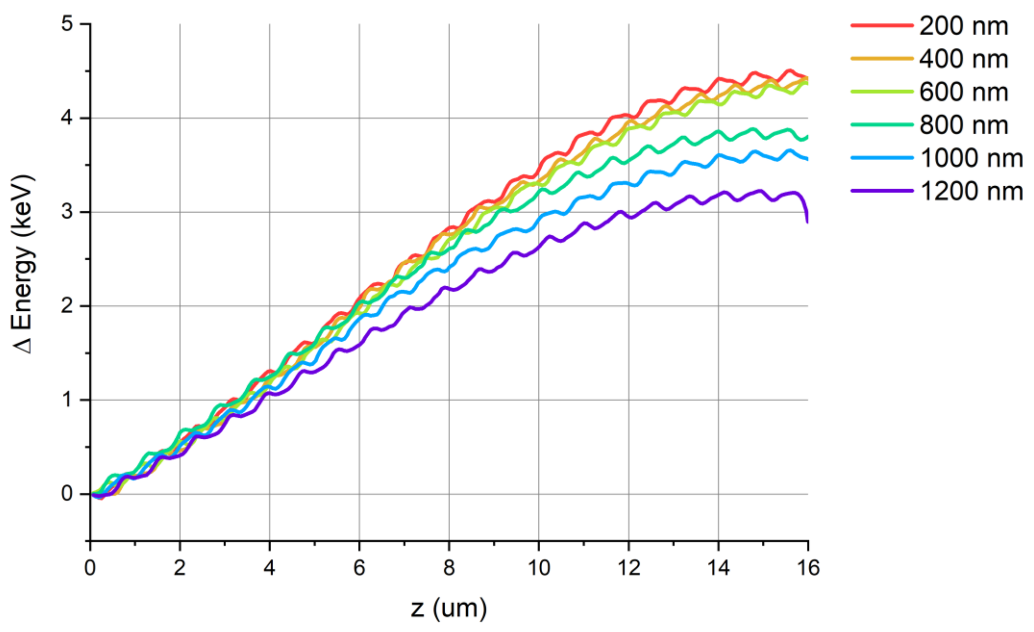
Gauss wave



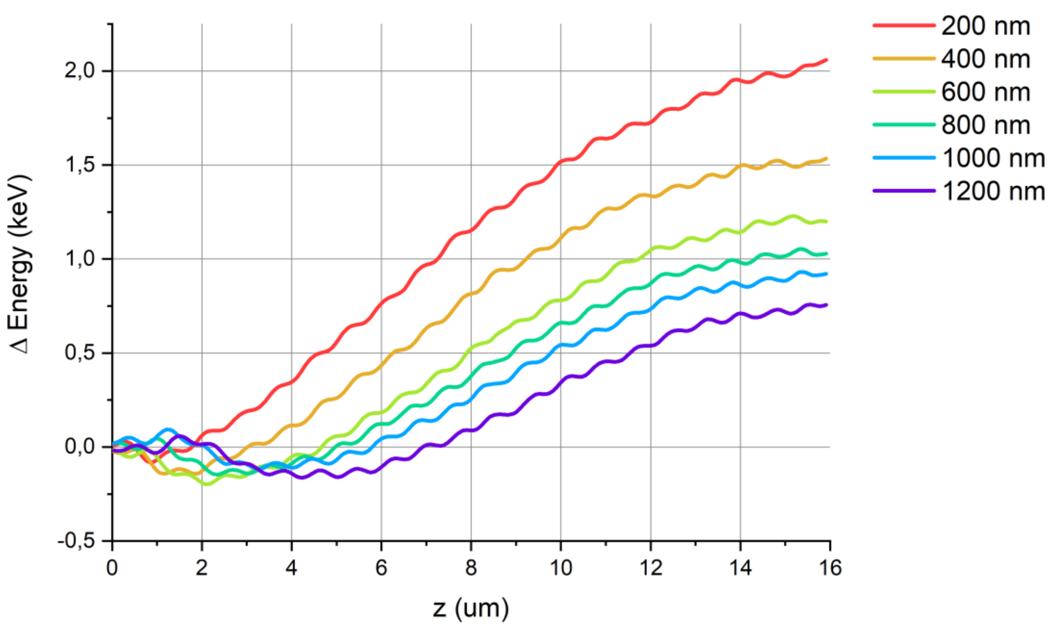
Average increase in electron energy for different beam heights over a rectangular structure

$E_0 = 2.1$ MeV

Plane wave



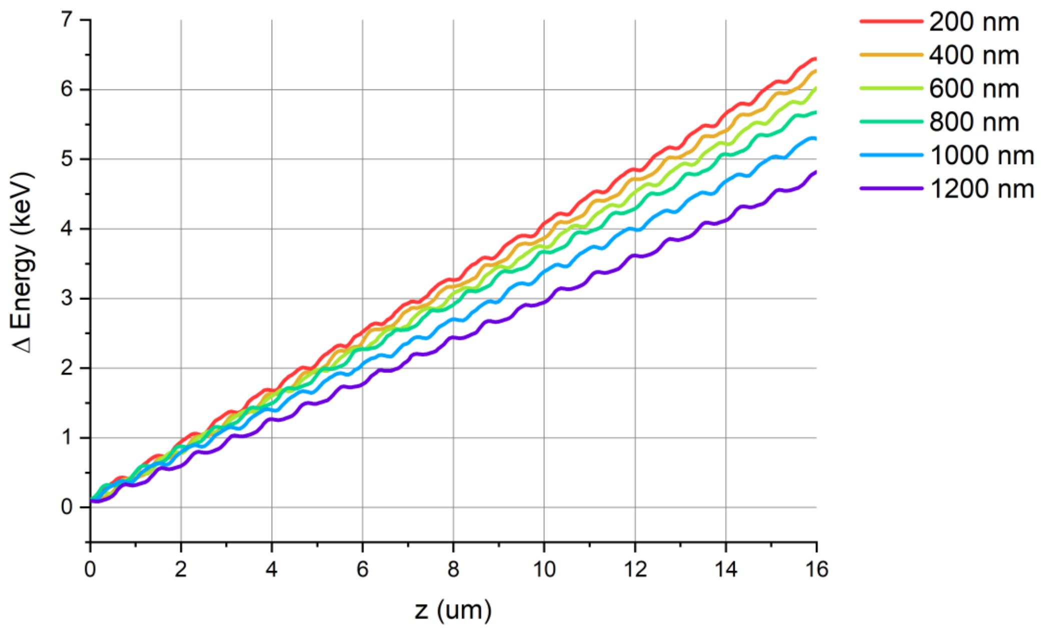
Gauss wave



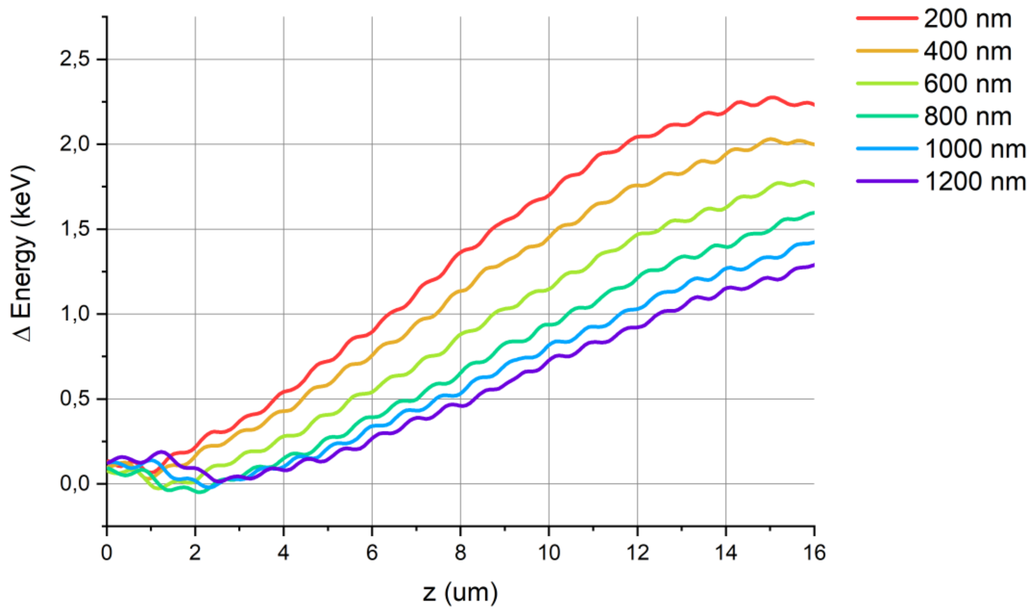
Average increase in electron energy for different beam heights over a rectangular structure

$E_0 = 50$ MeV

Plane wave



Gauss wave



Acceleration gradients for different profiles

Beam height y, nm	2.1 MeV									
	Gradient for plane wave, MeV/m					Gradient for gauss beam, MeV/m				
	1	2	3	4	5	1	2	3	4	5
200	313	266	271	248	119	150	158	142	150	70
400	306	259	251	244	118	112	111	104	103	48
600	300	241	228	241	116	84	81	75	75	36
800	281	216	209	221	110	76	69	64	62	33
1000	256	199	191	196	91	68	60	57	53	26
1200	234	182	168	179	85	56	47	48	42	20

1 – Rectangular, 2 – Cylindrical, 3 – Grooves, 4 – Sinusoidal, 5 – Triangular

Acceleration gradients for different profiles

Beam height y, nm	50 MeV									
	Gradient for plane wave, MeV/m					Gradient for gauss beam, MeV/m				
	1	2	3	4	5	1	2	3	4	5
200	413	350	350	331	163	151	130	111	116	62
400	400	331	325	319	153	134	110	104	100	52
600	388	313	300	306	145	117	94	97	84	41
800	363	288	275	286	141	104	83	86	76	36
1000	338	256	238	264	129	97	78	79	70	33
1200	313	225	204	238	115	86	68	74	59	29

1 – Rectangular, 2 – Cylindrical, 3 – Grooves, 4 – Sinusoidal, 5 – Triangular

Conclusions

- As expected, when the parameters in the simulation approached the real experiment, and the excitation of the structure by a Gaussian wave gave lower acceleration rates than when simulating the excitation of the structure by a plane wave.
- Comparative analysis shows that in almost all cases the rectangular structure shows the best result, at y = 200 for electrons with an energy of 50 MϵV and excitation of the structure by a Gaussian wave, the cylindrical structure turned out to be 14% worse, the grooves and sinusoidal showed deterioration by 24% and 27% accordingly, the triangular one showed the worst result - acceleration is 59% lower.
- Commercially available diffraction gratings (for example, grooves) also provide a fairly high acceleration rate and can be used for experiments.

Thanks for attention!