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THE REAL SCIENCE

ALUMINIUM NITRIDE THIN FILMS SURFACE SMOOTHING BY ARGON CLUSTER IONS

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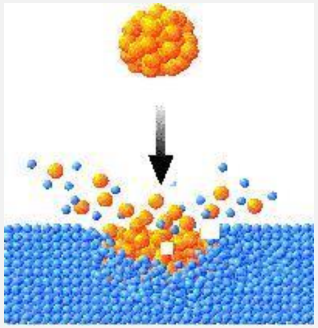
ADVANTAGES OF THE CLUSTER ION BEAM

Gas Cluster Ion Beam (GCIB) **Monomer ion beam**



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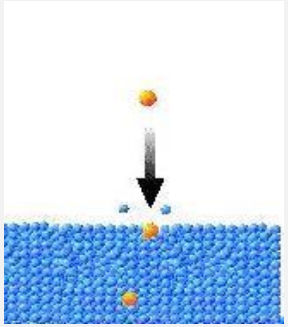


Collectively interaction **Binary collisions**

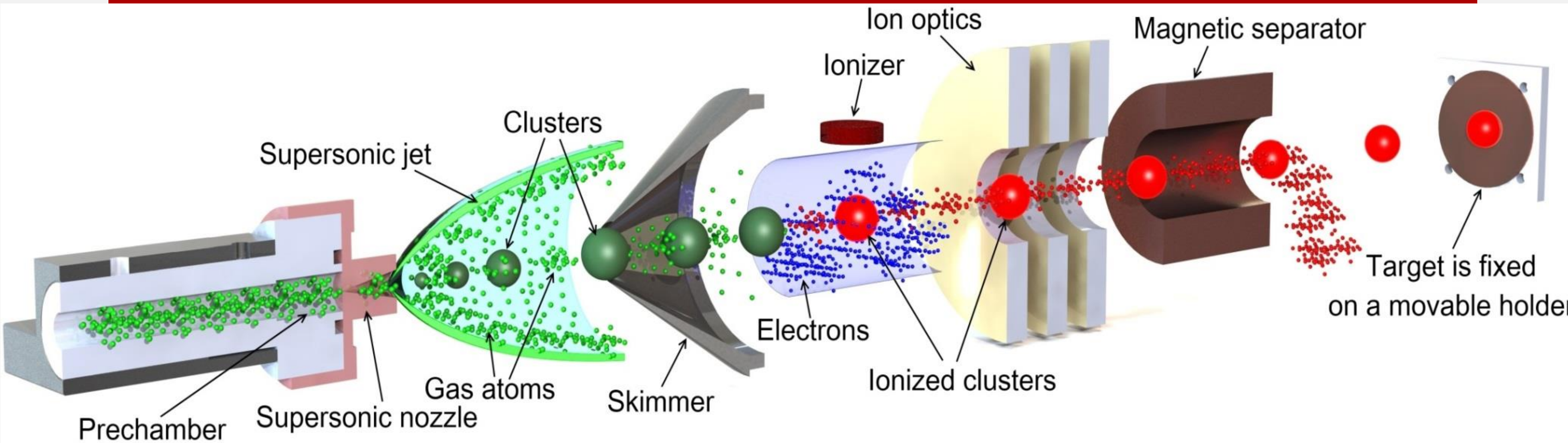
Complex nonlinear effects:

- local high density of energy deposition (local temperature up to 10^5 K, pressure up to 10 Mbar) in the subsurface layer, less than 20 nm deep;
- lateral sputtering leading to surface smoothing;
- the energy per atom in a cluster can reach values <10 eV, which is comparable with the binding energy of atoms on the target surface, what leading to minimal damage to the subsurface material structure; this energy is unattainable in monomer ion beams.

Material processing:

- surface smoothing and etching with low damage;
- the formation of self-organizing nanostructures;
- subsurface implantation;
- deposition of thin films.

- **Material surface diagnostics:** secondary ion mass spectrometry using cluster ions (GCIB-SIMS).



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Main tasks and problems:

- Formation of a neutral cluster beam with the required cluster size and maximum intensity
- Highly efficient electron beam ionization of neutral clusters with minimal fragmentation
- Acceleration and focusing of cluster ion beam
- Separation of oligomer and monomers ions and and transport of cluster ions to the target
- **Formation of cluster ion beam with defined parameters (mean size, energy per atom in cluster)**

EXPERIMENTAL SETUP "CLIUS"

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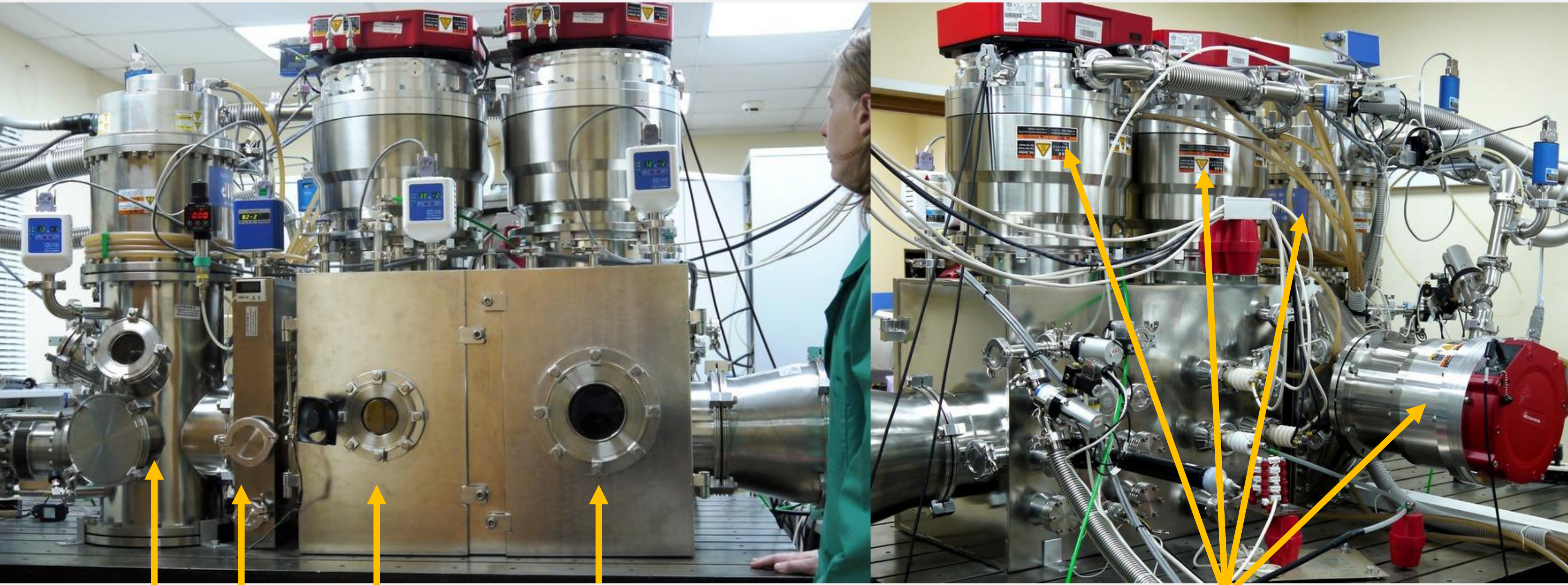


Experiment parameters:

Working gas: Argon

Cluster energy: 5-23.5 keV

Mean cluster size: 180-1000 atoms/cluster

THE MAIN PARAMETERS OF THE TREATMENT MODES

Treatment mode	Mean cluster size N, atoms/cluster	Cluster ions energy E, keV	Energy per atom E/N, eV/atom	Ion fluence, ions/cm^2
1 (high-energy)	210	22	105	8.1×10^{15}
2 (low-energy)	1000	10	10	2.2×10^{16}

$$Y = \frac{N_{OUT}}{N_{IN}}$$

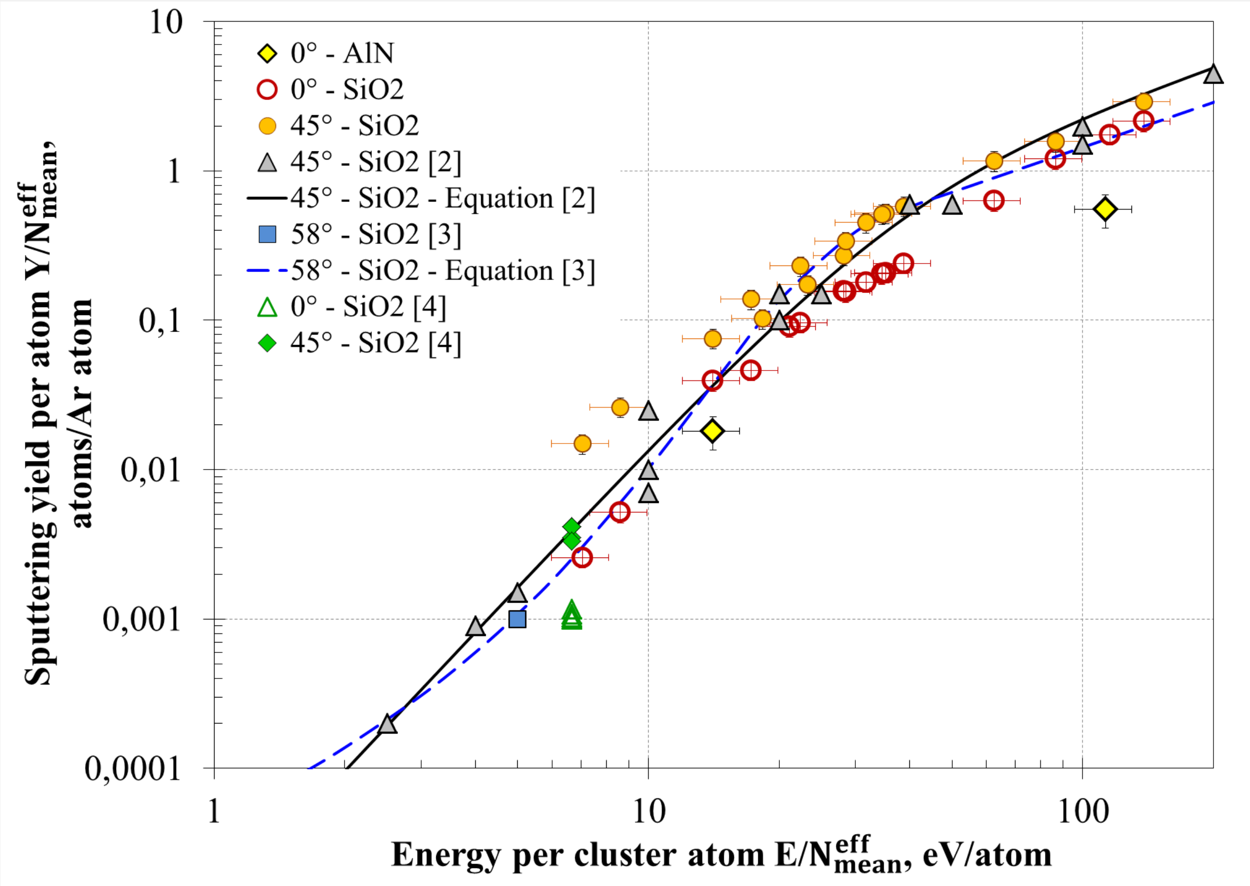
where N_{OUT} – the total number of sputtered target atoms during cluster bombardment Ar^{+};
N_{IN} – the total number of Ar + cluster ions during the exposure;

Previously, in [1], we have shown that, at the normal incident angle of clusters, the GCIB sputtering process is determined by the energy per atom in the cluster *E*/*N*. Thus, as well as for oblique angles of incidence [2,3], the sputtering yields *Y* can be described as a universal nonlinear equation *Y*/*N* vs. *E*/*N* for clusters incident at a normal angle.

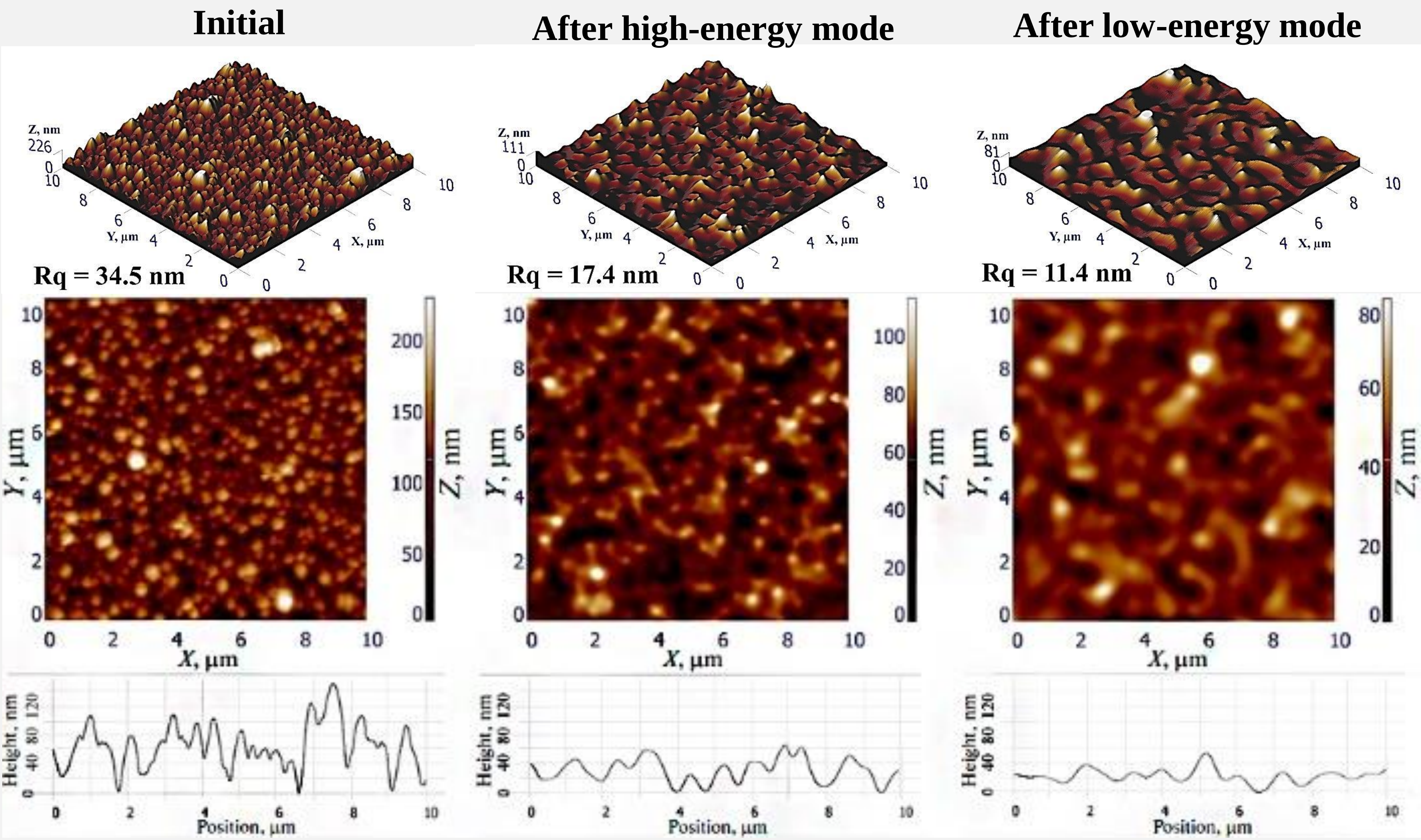
$$\frac{Y}{N} = \frac{(E/(AN))^{q}}{1 + (E/(AN))^{q-1}}$$ [2]

$$\frac{Y}{N} = EA\left[1 + erf\left(\frac{E-U}{s}\right)\right]$$ [3]

where *N* – mean cluster size, atoms;
E – kinetic cluster energy, eV;
A, q, U, s – constants for specific materials.

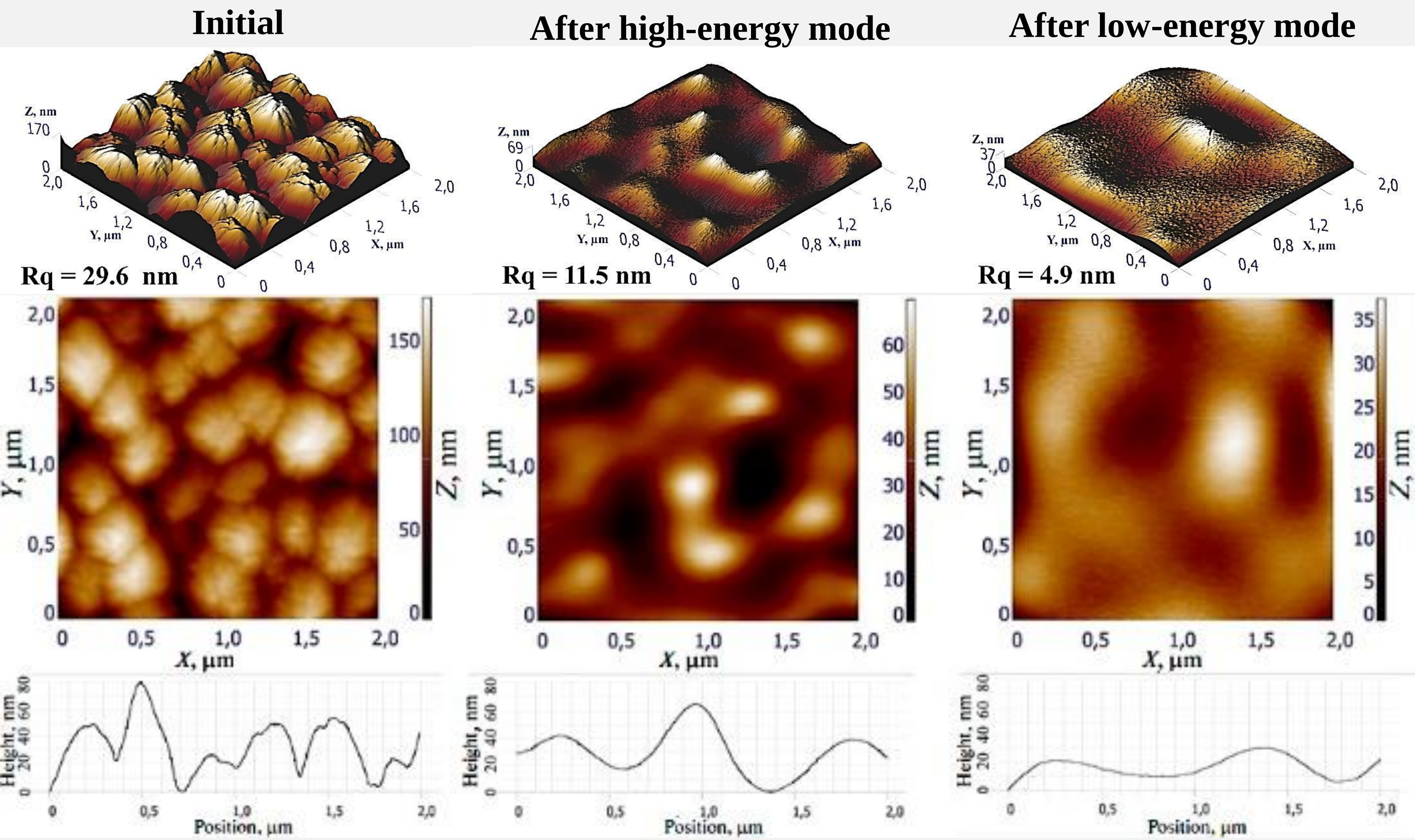


[1] N.G. Korobeishchikov et al. *Applied Physics A* 124 (2018) 833
[2] M.P. Seah. *J. Phys. Chem. C* 117 (2013) 12622
[3] P.J. Cumpson et al. *J. Appl. Phys.* 114 (2013) 124313
[4] K Sumie et al. Nucl. Instr. Meth. Phys. Res. B 307 (2013) 290



AFM images of AlN thin film surface at scan sizes 10×10 μm²: initial and after cluster ions treatment.

AFM 2×2 μm²



AFM images of AlN thin film surface at scan sizes 2×2 μm²: initial and after cluster ions treatment.

To comparing the effectiveness of various treatment modes, it should be noted that the sputtering depth was 90 and 30 nm for modes 1 and 2, respectively.

Treatment mode	**RMS roughness R_q, nm**	**Maximum roughness R_t, nm**
Scan size 2×2 μm²		
initial	29.2	169
after mode 1	9.9	61
after mode 2	**4.9**	**35**
Scan size 10×10 μm²		
initial	35.0	222
after mode 1	16.8	107
after mode 2	**11.3**	**78**
Scan size 40×40 μm²		
initial	26.4	176
after mode 1	14.3	97
after mode 2	**11.1**	**74**
Scan size 100×100 μm²		
initial	21.3	144
after mode 1	12.3	92
after mode 2	**9.5**	**63**

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CONCLUSIONS

- The surface treatment of a polycrystalline AlN thin film with argon cluster ions was performed in various experimental modes. The possibility of effective smoothing of a nanostructured AlN surface with a minimum depth of the sputtering layer and minimal damage to the subsurface structure of the processed material is proved.

- It was shown that, after treatment mode 2, the root–mean–square roughness decreased in 2.2–6 times (depending on the scan size).

- The highest efficient smoothing with very small sputtering depth (tens nm) is obtained in the low–energy treatment modes (few eV/atom), which is caused by active lateral displacement of subsurface target atoms.

Thank you for your attention!