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INFLUECNE OF SHORT-PULSED ION IRRADIATION ON THE OPTICAL PROPERTIES OF Al-Si-N COATINGS

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Abstract. The report presents the results of the effect of irradiation with high intense pulsed ion beam (HIPIB) with parameters: pulse duration – 90 ns, accelerating voltage – 200 kV, beam composition – C^+/H^+ - 85/15 %); on optical and electrical properties of aluminum nitride films and nanocomposite Al–Si–N coatings with a various Si content deposited by a reactive magnetron sputtering onto a silicon substrate.

Materials and methods

AlN films, Al–Si–N films with different Si content (10 at.% (Al-Si-N 90/10), 30 at.% (Al-Si-N 70/30) and 96 at.% (Al- Si-N 4/96)) deposited on silicon single crystal substrates by reactive magnetron sputtering. Thickness of films were d = 1.9–2.8 μm and did not change after irradiation.

Optical measurements:

were made by Avaspec 2048 spectrometer in the energy range hν = 1.3–3.6 eV.

The spectral dependences of the absorption coefficient α (hν) were obtained from the diffuse reflection spectra R (hν) according to the relation: $\boldsymbol{\alpha (h\nu) = (1 / d) \times (1\text{-}R (h\nu))^2 / R (h\nu)}$.

The spectra were approximated by the Urbach rule $\boldsymbol{\alpha (h\nu) \sim \exp (h\nu/E_U)}$ in energy ranges Δ (hν), in which lnα ~ hν (E_U - Urbach energy).

The parameters of the interband absorption were determined by approximation of the spectra by the power law: $\boldsymbol{(\alpha \times h\nu) \sim (h\nu - E_g' (E_g''))^m}$ - where m = 1/2 and 2 were corresponded to direct and indirect allowed interband transitions.

The relative integral radiation sensitivity $\boldsymbol{S = \Delta\alpha_i / \alpha_0}$, calculated by averaging the values $\Delta\alpha_i$ (hν) and α_0 (hν) in the range 1.3–3.6 eV – key parameter of radiation stability.

Surface conductivity σ was measured by the method of applied electrodes.

Irradiation parameters:

Beam composition - C^+/H^+ (85%/15%).
Pulse duration – 100 ns.
Accelerating voltage – 200 kV.
Number of pulses – 1-6, 60 and 180.

Two modes with different energy densities Jp:
0.35 J/cm^2 – equal to 3 MGy per pulse,
0.75 J/cm^2 – equal to 7 MGy per pulse.

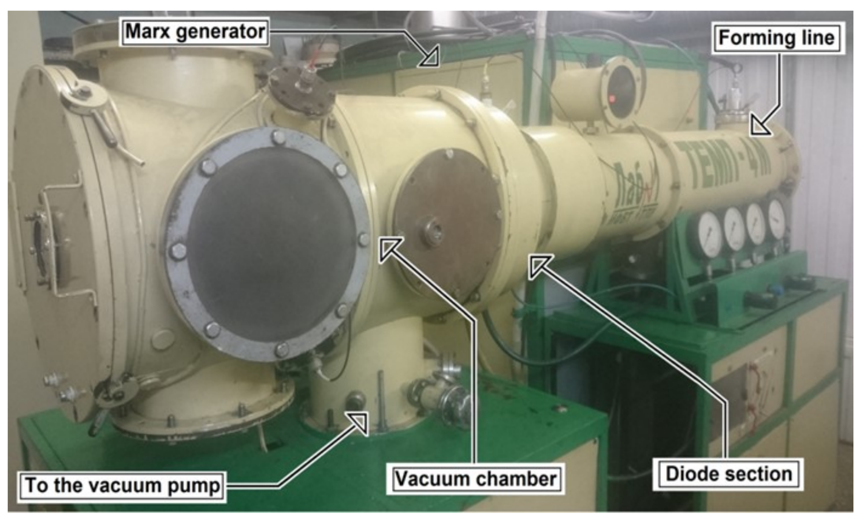

Fig. 1. Temp-4M ion accelerator

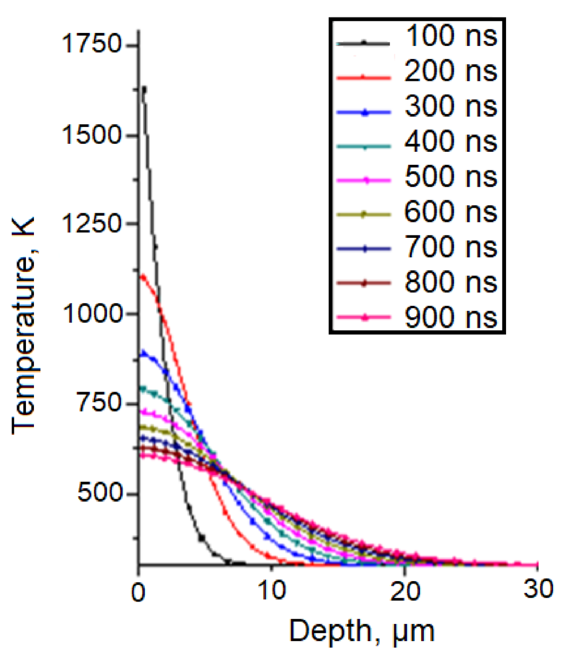

Fig. 2. Evolution of temperature fields in the silicon sample during and after the pulse of HIPIB. Pulse duration – 150 ns, 250 keV C^+, energy density 0.35 J/cm^2.

HIPIB introduce radiation defects and annihilate radiation and grown defects by thermal-annealing process.

Results

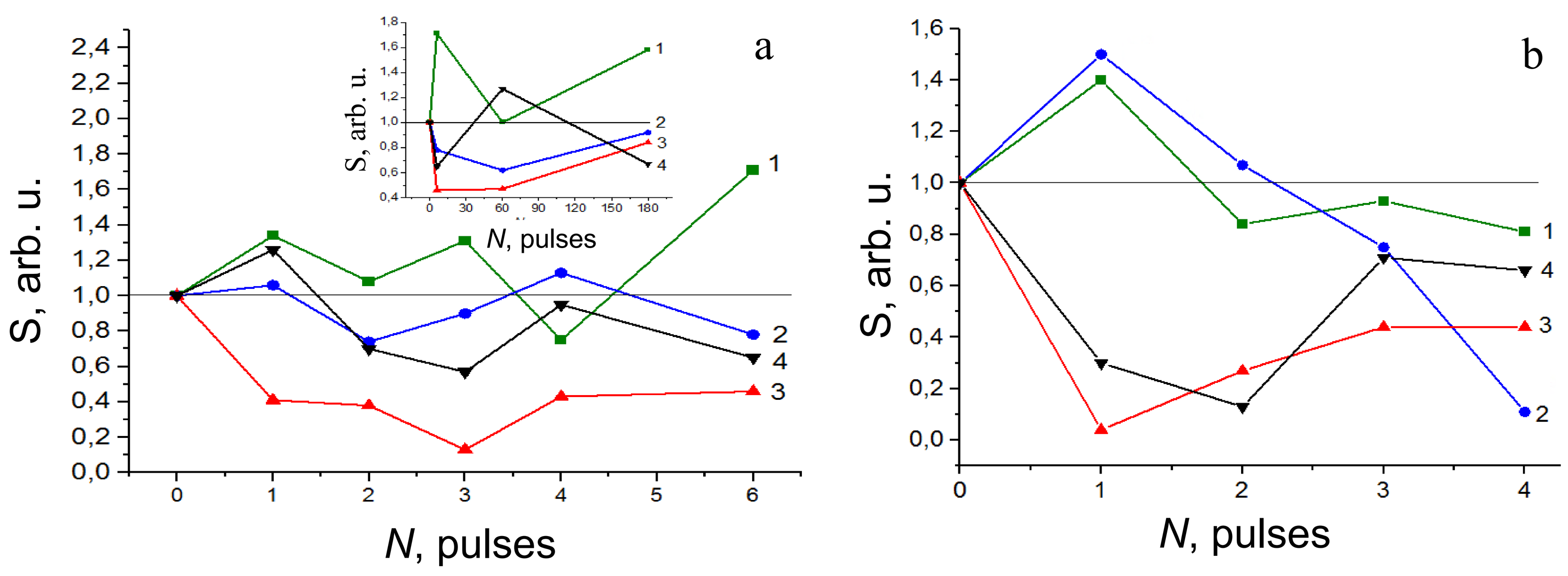

Fig. 3. Effect of ion dose D on the relative integral radiation sensitivity $S = \Delta\alpha_i / \alpha_0$ of aluminum nitride films (1) and Al-Si-N 90/10 (2), Al-Si-N 70/30 (3) and Al -Si-N 4/96 (4) films deposited on a silicon substrate at a beam energy density J_p = 0.35 J/cm^2 (a) and 0.75 J/cm^2 (b).

Short-pulsed irradiation with carbon ions of the coatings is accompanied by intense radiation and thermal annealing of unstable growth and primary radiation intrinsic defects and their redistribution at the first stage of irradiation with 1–4 (5) pulses (equal to doses of 3–30 MGy) and the formation of thermostable defect complexes at the second stage of irradiation at doses of 20–600 MGy. The effect of radiation and thermal annealing on properties increased with increasing beam energy.

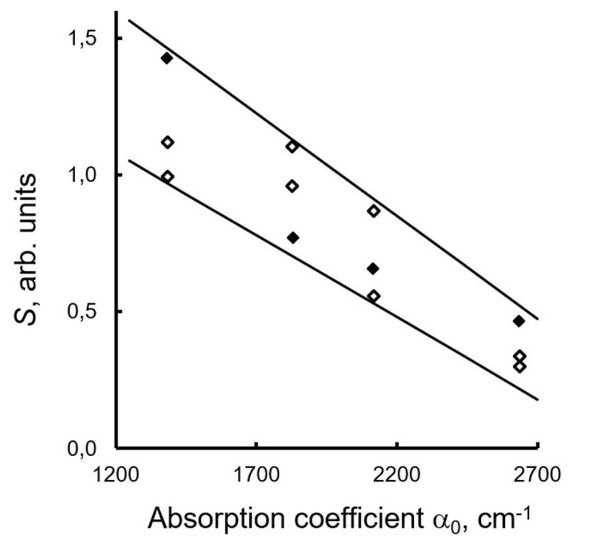

Fig. 4. Relationship between the radiation sensitivity $S = \Delta\alpha_i/\alpha_0$ and the initial absorption coefficient α_0 of AlN films and Al–Si–N films with doses of 3–30 MGy (◊) and 6–600 MGy (♦).

A general tendency towards a decrease in radiation sensitivity with an increase in the absorbance of unirradiated films

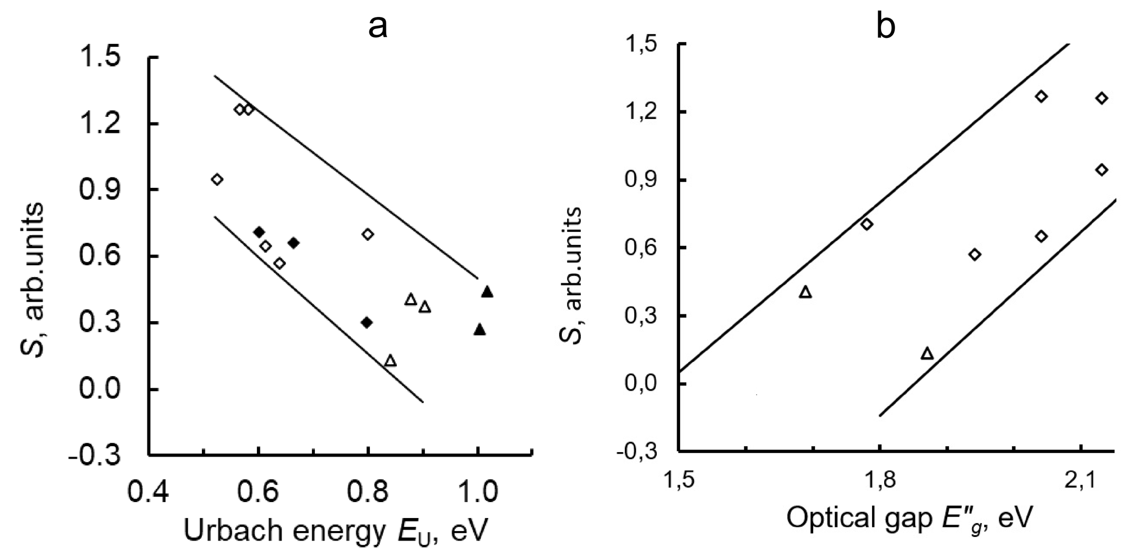

Fig. 5. Dependences of the relative integral radiation sensitivity $S = \Delta\alpha_i / \alpha_0$ on the Urbach energy E_U (a) and optical gap (b) in Al-Si-N 70/30 and Al-Si-N 4/96 coatings irradiated with carbon ions in the mode of short-pulse implantation. Designations: Al-Si-N 4/96 (◊, ♦), Al-Si-N 70/30 (Δ, ▲); Jp = 0.35 J/cm^2 (◊, Δ) and 0.75 J/cm^2 (♦, ▲).

An increase in the degree of overlap between the levels of defects which is proportionally to the Urbach energy is accompanied by a decrease in the radiation sensitivity of the coatings, that is, an increase in their radiation resistance.

The relationship between the radiation sensitivity of the Al-Si-N 70/30 and Al-Si-N 4/96 coatings and the change in their optical gap for indirect interband transitions S (E"$_g$) is opposite.

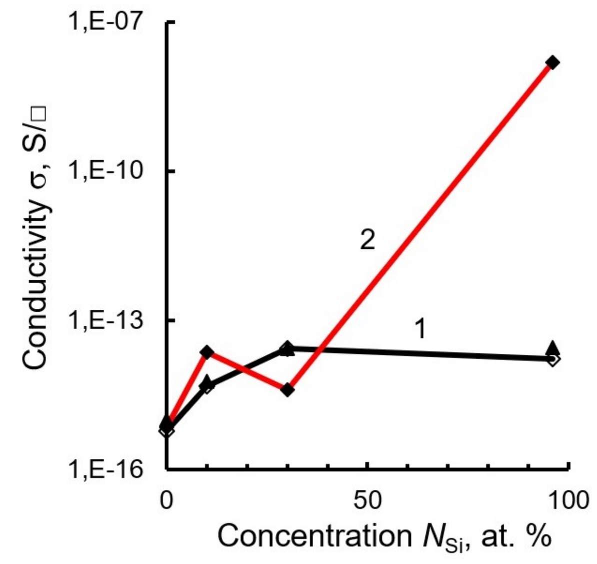

Fig. 6. Effect of the silicon content N_{Si} in films on their surface conductivity □ before (1) and after irradiation with dose of 600 MGy (2)

Films have a very low surface electrical conductivity s ≤ 10^{-14} S/□ due to the low mobility of charge carriers due to the scattering effect of grain boundaries. With an increase in the silicon content from 0 to 96 at.%, the electrical conductivity of the coatings increases from 7 × 10^{-16} S/□ to 3 × 10^{-14} S/□. This suggests that silicon containing defects with shallow energy levels make the main contribution in charge transport. The electrical conductivity of AlN, Al-Si-N 90/10, Al-Si-N 70/30 films changes insignificantly when they are irradiated with ions. The introduction of deep levels of radiation defects, which play the role of trapping and localization centers of charge carriers, is not able to significantly increase the electrical conductivity. An increase in the electrical conductivity of the Al-Si-N 4/96 films from $3{\cdot}10^{-14}$ S/□ to 10^{-8} S/□ after a dose of 600 MGy is caused by the appearance of shallow electrically active levels of radiation defects inherent in silicon nitride. In general, the stability of the electrical characteristics of AlN and Al-Si-N films confirms their radiation stability.

Conclusions

1) Nonmonotonic dependence of the rate of induced of defects on the irradiation dose.

2) Radiation sensitivity of the films decreases with the increasing of Urbach energy and initial absorption coefficient and increases with increasing of the optical gap.

3) Films have a very low surface electrical conductivity. Si-based defects and complexes induced under irradiation can significantly increase the conductivity.

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