In situ video recording of crystallization of amorphous Sb_2Se_3 films

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During thermal evaporation in vacuum of a powder weight of antimony selenide amorphous film is formed on substrate at a room temperature (Fig.1a). Electron irradiation of a free-standing amorphous film with a dose rate ~ $6 \cdot 10^4$ $e^-/Å^2 \cdot s$ inside the column of the electron microscope causes its crystallization due to Joule-Lenz heating (Fig. 1b, c, d and Table 1). In situ electron microscopy studies with the video recording method demonstrated, that a-c phase transformation is described with the island polymorphous crystallization mode with the relative length $\delta_0 \approx 196$.

The dependence on time of the crystallized volume fraction $x(t)$ in amorphous Sb_2Se_3 film has an exponential character (Fig.3), described by the JMAK formula (1). The formation of the polycrystalline film occurs at the constant crystal growth rate and constant nucleation rate (Table 2), that corresponds to the α-version of the Kolmogorov model (continuous nucleation process). According to (1) the Avrami exponent $n = 2.16$ (nearest integer = 2).

$$x(t) = 1\text{-}\exp(-0.08733t^{2.16}) \quad (1)$$

These values of n are typical for the crystallization process in which grain growth occurs with nucleation. Values n where nearest integer = 2, took place during crystallization of thin amorphous films of Ta_2O_5, Yb_2O_2S, V_2O_3.

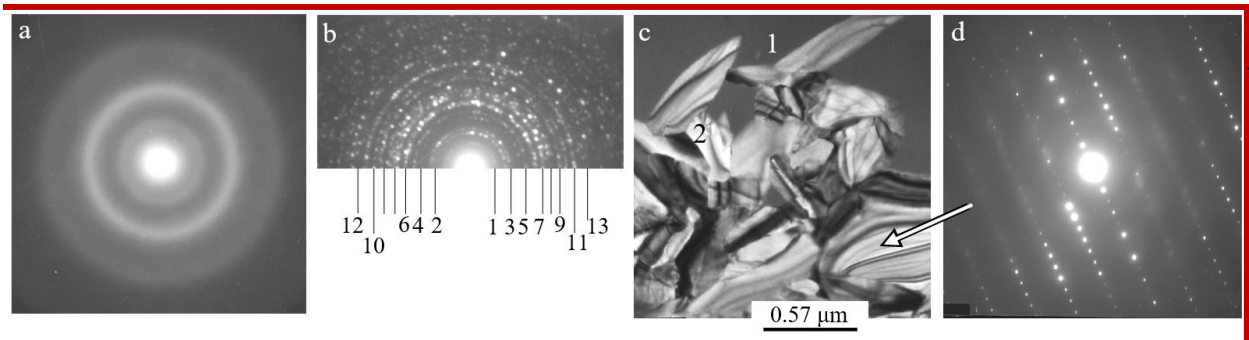

Fig. 1. Crystallization of the amorphous Sb_2Se_3 film: (a). a - electron diffraction pattern at the initial state; b - the same after partial crystallization by the electron beam; c - TEM image of the partially crystallized film (1-amorphous phase, 2-crystalline phase); d - SAED pattern from the grain of Sb_2Se_3

Table 1. Decoding of the SAED at Fig. 1b

Diffraction ring number	*hkl*
1	110
2	020
3	120
4	220
5	310
6	211
7	221
8	321
9	510
10	520
11	002
12	600
13	360

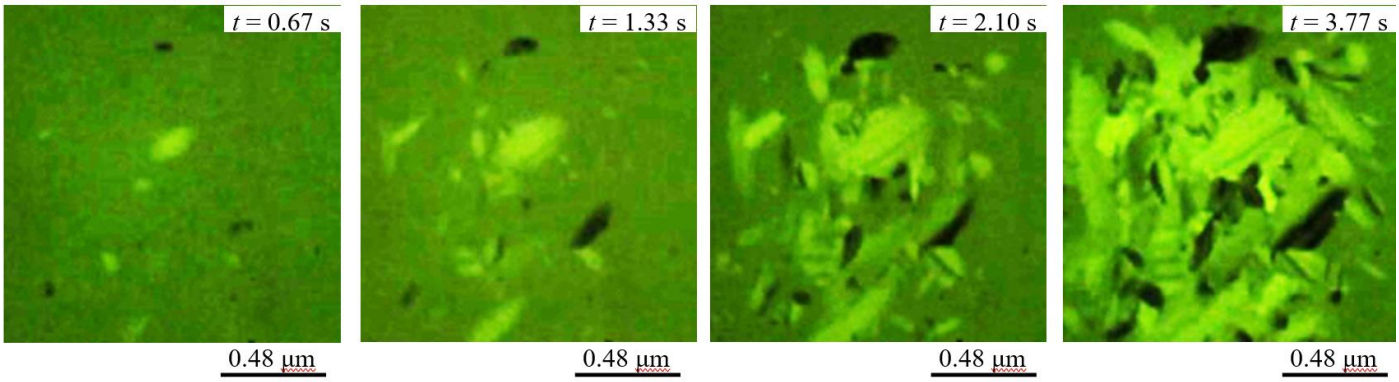

Fig. 2. Video frames of crystal growth in amorphous films of Sb_2Se_3 at electron beam irradiation. Time moments *t*, that has passed from the beginning of the recording of the crystallization process, are shown in the upper right corner of each frame

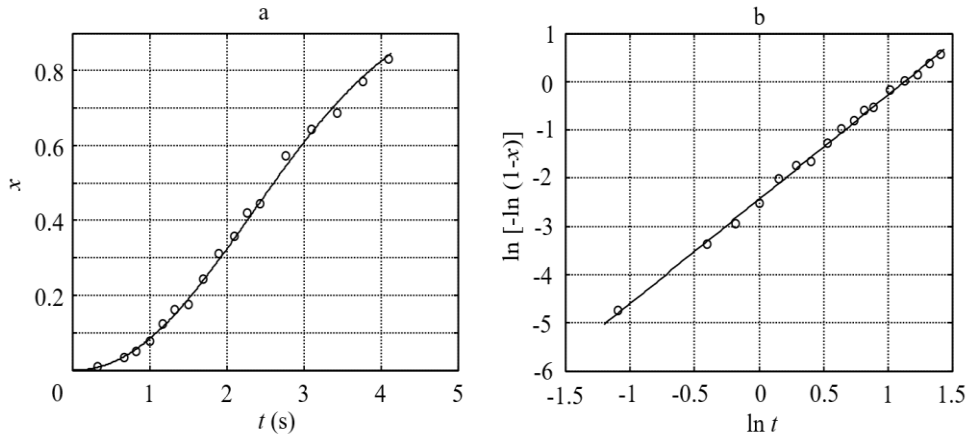

Fig. 3. The dependence on time of the crystallized volume fraction $x(t)$ in amorphous Sb_2Se_3 film in coordinates x - t (a) and in coordinates $\ln[-\ln(1-x)] - \ln t$ (b)

Table 2. Parameters of the electron beam induced crystallization of amorphous films of Sb_2Se_3*

h (nm)	30
$\langle v_\tau \rangle$ (μm/s)	0.0519
t_0 (s)	3.09
D_0 (μm)	0.16
n	2.16
k (s^{-2})	0.08733
α ($cm^{-2} \cdot s^{-1}$)	$7.41 \cdot 10^8$
δ_0	196

*h is the thickness of the film, $\langle v_\tau \rangle$ is the average tangential growth rate of the crystals, t_0 is the characteristic time unit, D_0 is the characteristic length unit, n is the Avrami exponent, k is the rate constant, α is the nucleation rate, δ_0 is the relative length.