

Crystallization modes of amorphous films and their numerical characteristic according to TEM data

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Based on “in situ” electron microscopic studies with the method of video recording of phase transformations, following polymorphous crystallization modes [1] in amorphous films have been identified according to their structural and morphological characteristics (Table 1). The possibility of using of the relative length δ_0 as a numerical parameter, characterizing each crystallization mode, was considered.

Layer polymorphous crystallization (LPC) mode describes the nucleation and growth of a single-crystal layer in the field of the electron-beam impact on amorphous film (Fig. 1a). In this case $\delta_0 = D_0/a_0$, where a_0 is a cell parameter of the growing crystal. D_0 is an average crystal size at a time $t = t_0$ (t_0 is characteristic unit of time), after which the volume of the amorphous phase decreases by the factor of $e = 2.718$. For LPC mode δ_0 is about several thousand (2000-5000).

Island polymorphous crystallization (IPC) mode describes the nucleation and growth of a polycrystalline layer (Fig. 1b). In this case $\delta_0 = D_0/\Omega^{1/3}$, where Ω is the volume of the crystal unit cell. For IPC mode δ_0 is about several hundred (100-1100).

Intermediate mode between LPC and IPC. It occurs when several (2 - 4) crystals grow in the zone of exposure to the electron beam. For this case $\delta_0 \sim 1100-2000$.

Dendrite polymorphous crystallization (DPC) mode describes the nucleation and growth of dendrite in amorphous layer (Fig. 1c). In this case also $\delta_0 = D_0/\Omega^{1/3}$, where Ω is the volume of the crystal unit cell. For DPC mode $\delta_0 \sim 3868$.

Table 1. Crystallization modes in amorphous films

Crystallization mode	Film	Deposition method	δ_0
LPC	Sb ₂ S ₃	Thermal evaporation	4992
	Cr ₂ O ₃	Laser evaporation	3107
	V ₂ O ₃	Laser evaporation	4553
	Ta ₂ O ₅	Laser evaporation	3659
IPC	ZrO ₂	Ion-plasma evaporation	118
	ZrO ₂	Laser evaporation	904
	Ta ₂ O ₅	Laser evaporation	416
	V ₂ O ₃	Laser evaporation	1024
	Yb ₂ O ₂ S	Electron beam evaporation	1030
Intermediate	Ta ₂ O ₅	Laser evaporation	1783
DPC	HfO ₂	Laser evaporation	3868

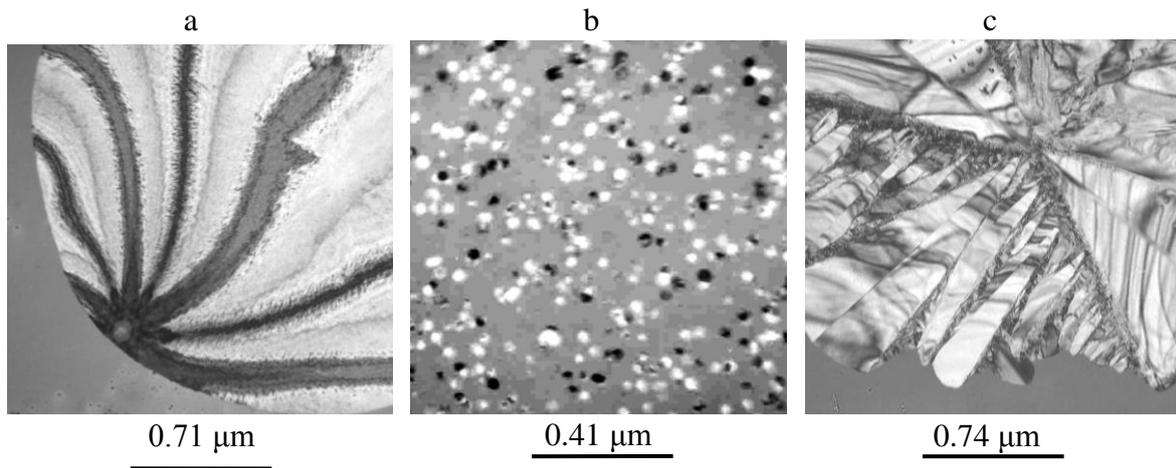


Fig. 1. TEM images of crystallization modes in amorphous films:
LPC of Ta_2O_5 (a), IPC of ZrO_2 (b) and DPC of HfO_2 (c)

[1] A.G. Bagmut, *Functional Materials*. **26**, 6 (2019).