TEM studies of unusual lattice bending in the crystallites formed in amorphous films by electron beam

Kolosov V Yu

Department of Physics, Institute of National Economy, 8-th March Street 62, Ekaterinburg (Sverdlovsk) 620219, Russia

Electron beam annealing is powerful method for local modifying and crystallization in desired modes of semiconductors and microelectronics components. An in-situ transmission electron microscopy (TEM) study was made which revealed a specific crystallographically unusual lattice ordering for Se crystals growing in thin amorphous films under the influence of electron beam[1]. The present paper carries some new data on the phenomenon of internal lattice bending for the growth of thin (300-1000 A) crystallites of Se, Te, α-Fe_2O_3, obtained by TEM. Bend-contour technique[2,3] was used to analyze the fields of lattice orientation in crystallites, including in-situ crystal growth studies and the analysis of the video records which will be presented. Selected area diffraction (SAD) and goniometric studies were used for additional confirmation of most principal results.

Internal lattice bending was observed for crystallites (in some cases dislocation-free single crystals), grown in flat unsupported amorphous films prepared by thermal evaporation or pyrolysis.

Internal lattice bending consists in the permanent regular rotation of the lattice at the front of a growing crystallite. It is realized about the axis or axes lying in the film plane and can amount to several complete rotations for a disk-shaped crystallite about 10-20 μm in diameter, Figs. 1, 2. The established internal lattice bending geometries (and not crystal buckling or morphology) are of the cylindrical, ellipsoidal (2 modifications) and toroidal type. Annealing or aging does not change such structures.

A lattice rotation versus growth rate curve with a maximum was revealed in most detailed studies of the Se and Fe_2O_3 crystal growth. Maximal lattice bending values near 100 degrees per mm are attained for Se at growth rate Vg near 1 μm/sec. The same extreme values are observed for other substances. They correspond to 2-4% elastic deformations (accomplished in surface layers) although large but possible for thin perfect crystals. The effect does not occur for small growth rates ($Vg < 0.01$ μm/sec for Se). The Vg of the crystallite, forming with lattice bending may be constant (for Se) or may vary rhythmically, synchronously with the change in lattice orientation at the growth front (for Fe_2O_3, Fig. 3). The crystallite with internal lattice bending can be formed by the help of focused electron beam at any desired point of the film, Fig. 4. The imperfection of formed crystallite depends upon electron beam intensity and focusing which determine the crystal growth rate.

Two models of the phenomenon are proposed. More promising is that based on the following facts testifying to surface nucleation: a) the presence of the preferential orientations of crystal nuclei revealed by SAD, b) an enhancement of TEM diffraction contrast of a crystal nucleus on the second frames of the video records discernible for large Vg in the range 10 - 500 μm/sec (bend-contour arrangement being the same). Owing to differences in the interatomic distances of bulk material and surface atoms, the surface nucleus relaxes to curved cluster and gives an impetus to lattice bending as the crystallite grows, Fig. 5.

Direct TEM evidence of an unusual and very strong internal lattice bending of thin microcrystallites grown in amorphous films by the help of an electron beam appears to be most important result.

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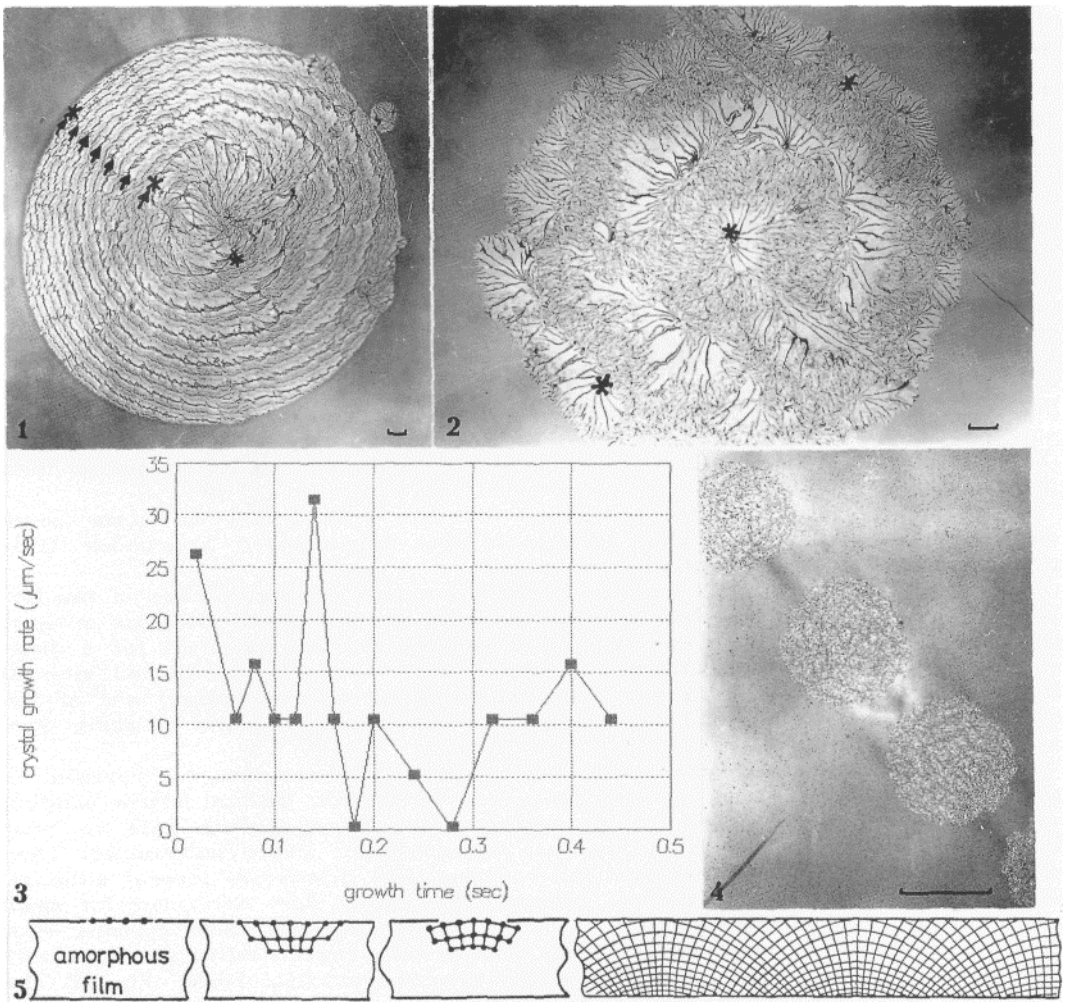

FIG. 1. Se spherulite, Vg=10 μm/sec. Different complex geometry of internal lattice bending at crystallite center and at periphery is revealed by analysis of bend-contour patterns. Lattice bending (rotation about [001], lying in the film plane) between any neighbour contrast lines, marked by arrows ([110] zone axis patterns) is 60°, between points marked by asterisks - 360°. Bar = 1 μm. FIG. 2. Fe_2O_3 crystallite. Average Vg exceeds 10 jam/sec, less for polycrystal concentric zones (dark on photo), more for single crystal zones in which [001] is nearly normal to film plane (light on photo). Lattice rotation of [001] between center of this crystallite and its periphery is realized in radial directions and exceeds 360° (misorientation of points marked by asterisks is 360°). Bar = 1μm. FIG. 3. Variation of crystal growth rate of Fe_2O_3 crystallite Vg with time, revealed from analysis of successive frames of video records. FIG. 4. Series of Fe_2O_3 crystallites formed by focused electron beam in amorphous film. The crystallite structure is similar to texture characterized for Fig. 2, but is less perfect and symmetric. Bar = 10 μm.
FIG. 5. Successive stages of formation of crystallite with internal lattice bending in proposed model (illustrated schematically in cross-section of thin film).