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Epitaxial growth of Mn_5Ge_3 on Si(111)

Ivan.A. Yakovlev*, Ivan.A. Tarasov
*-yia@iph.krasn.ru

Kirensky Institute of Physics, Federal Research Center KSC SB RAS,
Akademgorodok 50 bld. 38, 660036, Krasnokarsk, Russia

Abstract. The structure of Mn_5Ge_3 films deposited with and without different buffer layers on Si(111)7×7 substrates at a temperature of 390 °C are investigated by reflection high energy electron diffraction. It is shown that the 200 nm single-crystal germanide film is formed using two buffer layers with a slight manganese deficiency in the structure. But when deposition is without buffer layers, the thickness of a single-crystal film does not exceed 15 nm.

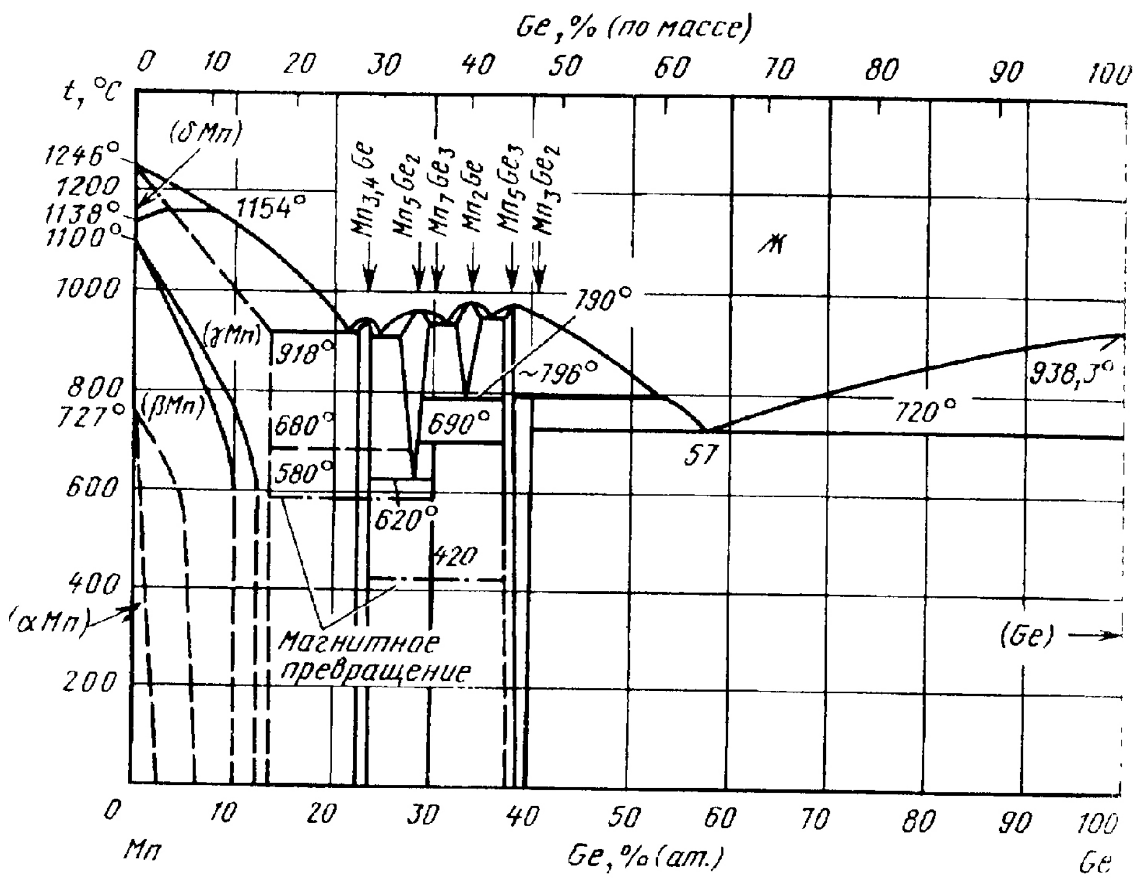


Fig.1. Bulk binary-phase diagram Mn/Ge

Table 1. Lattice parameter of Mn/Ge

Phase	Pearson sb, space group	lattice parameter, nm		
		a	b	c
Mn_5Ge_3	hP16, $P6_3/mcm$	0,7188 0,7184	— —	0,5037 0,5053
$Mn_{11}Ge_8$ (Mn_3Ge_2)	oP76, Pnma	1,322	1,583	0,509
$Mn_{3,4}Ge$(BT)*	hP8, $P6_3/mmc$	0,2668	—	0,43309
$Mn_{3,4}Ge$(HT)	tI8, I4/mmm	0,3803	—	0,3618
Mn_5Ge_2	hP128, $P\bar{3}c1$	0.7186	—	1,30

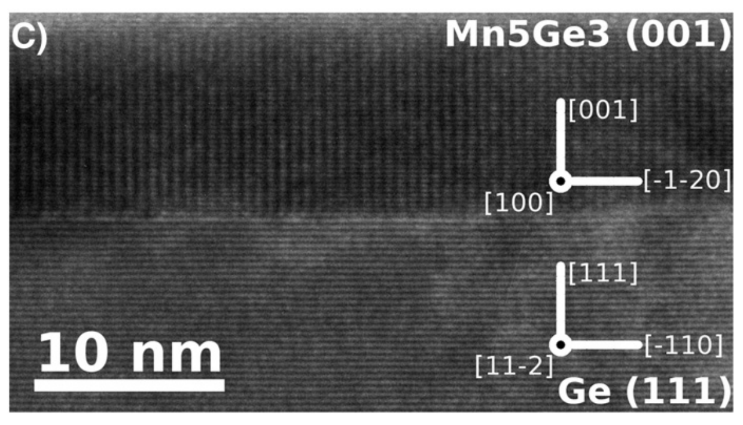
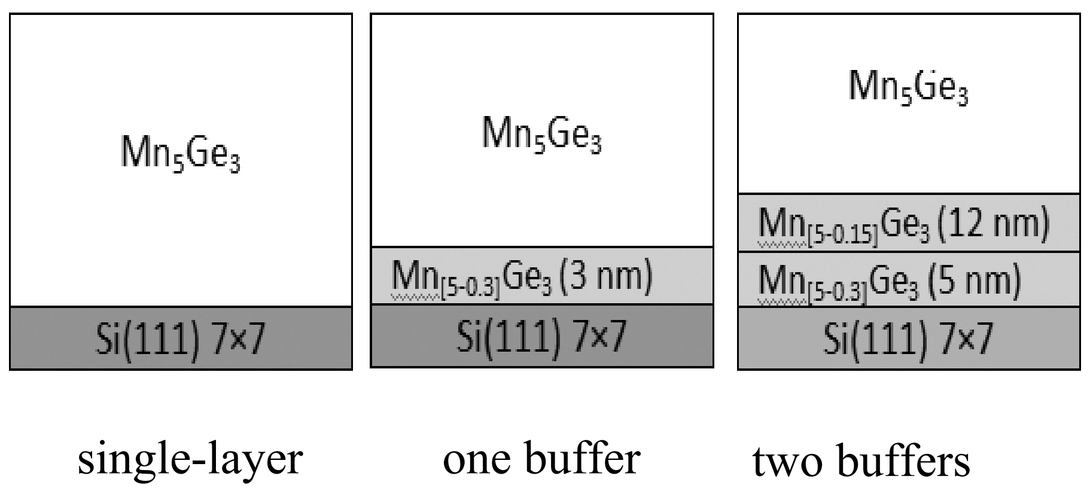


Fig.2. TEM cross sectional image of a Mn_5Ge_3 thin film showing an atomic flat interface.[1]

Experimental

The experiment was carried out with ultrahigh vacuum molecular-beam epitaxy “Angara” set-up [3], equipped with a system of reflection high-energy electron diffraction (RHEED). The base pressure in the growth chamber was 6.5×10^{-8} Pa. The 15mm*20 mm n-Si(111) substrates were used and prepared by special treatment [3] including annealing in vacuum at 1200 K. The component materials were evaporated from Knudsen effusion cells with BN-cricible.

The Mn_5Ge_3 films were prepared by molecular-beam epitaxy technique with simultaneous deposition of Mn and Ge on Si(111) 7×7 at 390 °C at different ratio of materials including stochiometric Mn_5Ge_3. The thickness of the films was in the range of 30-200 nm. The structure formation was monitored in situ by RHEED. In all experiments, the germanium deposition rate was 0.32 nm/min, and the manganese deposition rate varied from 0.28 to 0.30 nm/min. This rate range includes a flow ratio mode for obtaining a stoichiometric Mn_5Ge_3, which is V(Mn)/V(Ge)=0.926. In this work, a single-layer film of manganese germanide with the Mn_5Ge_3 stoichiometry was obtained, as well as two films with different Mn-Ge buffer layers close to Mn_5Ge_3 stoichiometry.



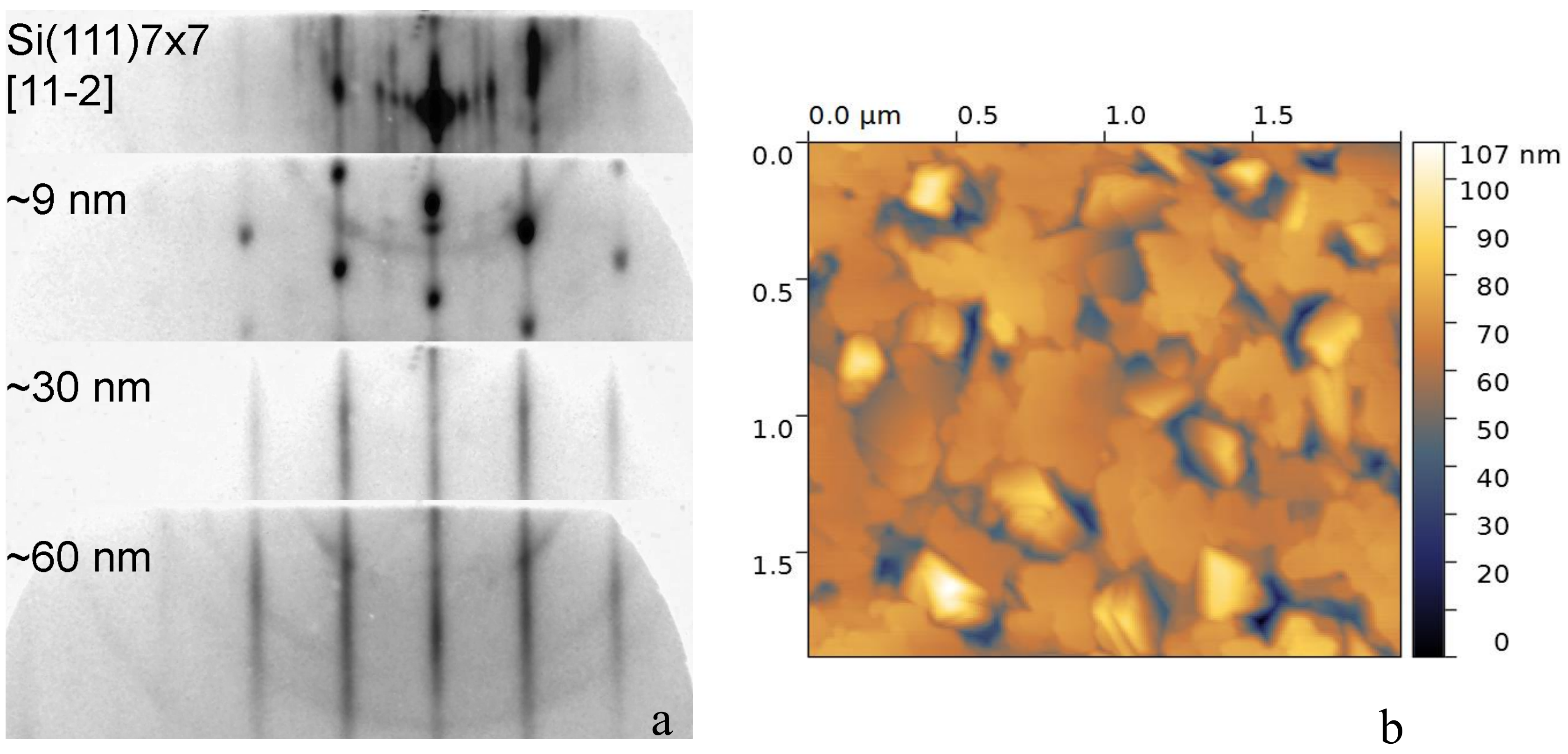


Fig.4. Mn_5Ge_3 film with one buffer layer: a) evolution of RHEED on total thickness; b) Atomic-force microscopy (AFM)

Acknowledgements

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[1] M. Petit, L. Michez, et al. Thin Solid Films 589 (2015) 427–432
[2]A. Alvídrez-Lechuga, J.T. Holguín-Momaca, et al. Superficies y vacio 30, no.4(2017)
[3] I.A. Yakovlev, S.N. Varnakov, B.A. Belyaev et al. JETP letters 99(9), 527 (2014).

Spintronics

The realization of practical spintronic devices requires an efficient electrical injection of spin-polarized electrons from a ferromagnet into the conduction band of a semiconductor, a subsequent spin-polarized detection as well as an effective manipulation of spin in the semiconducting channel. A perfect control of the growth process of the material layers and the interfaces between these layers will be required to manufacture efficient spintronic devices.

Mn_5Ge_3

The Mn_5Ge_3 presents all the prerequisite criteria necessary in spin devices: it is a well known ferromagnet (FM) with a magnetic ordering persisting up to the room temperature (T_C=297 K) with a magnetization of 1200 kAm^{-1}, and with an experimental spin polarization of P=15±5%. It has been demonstrated that Mn_5Ge_3 thin films could be grown epitaxially on a Ge(111) within a lattice mismatch of 3.7%. Mn_5Ge_3 has a hexagonal crystal structure$P6_3$/mcm, and lattice parameters a = 7.184 Å and c = 5.053 Å. The crystal structure is formed by two Mn sublattices: Mn I with atomic positions at (0.236, 0, 1/4), Mn II with atomic positions at (1/3, 2/3, 0) and Ge at (0.5991, 0, 1/4). [1, 2]

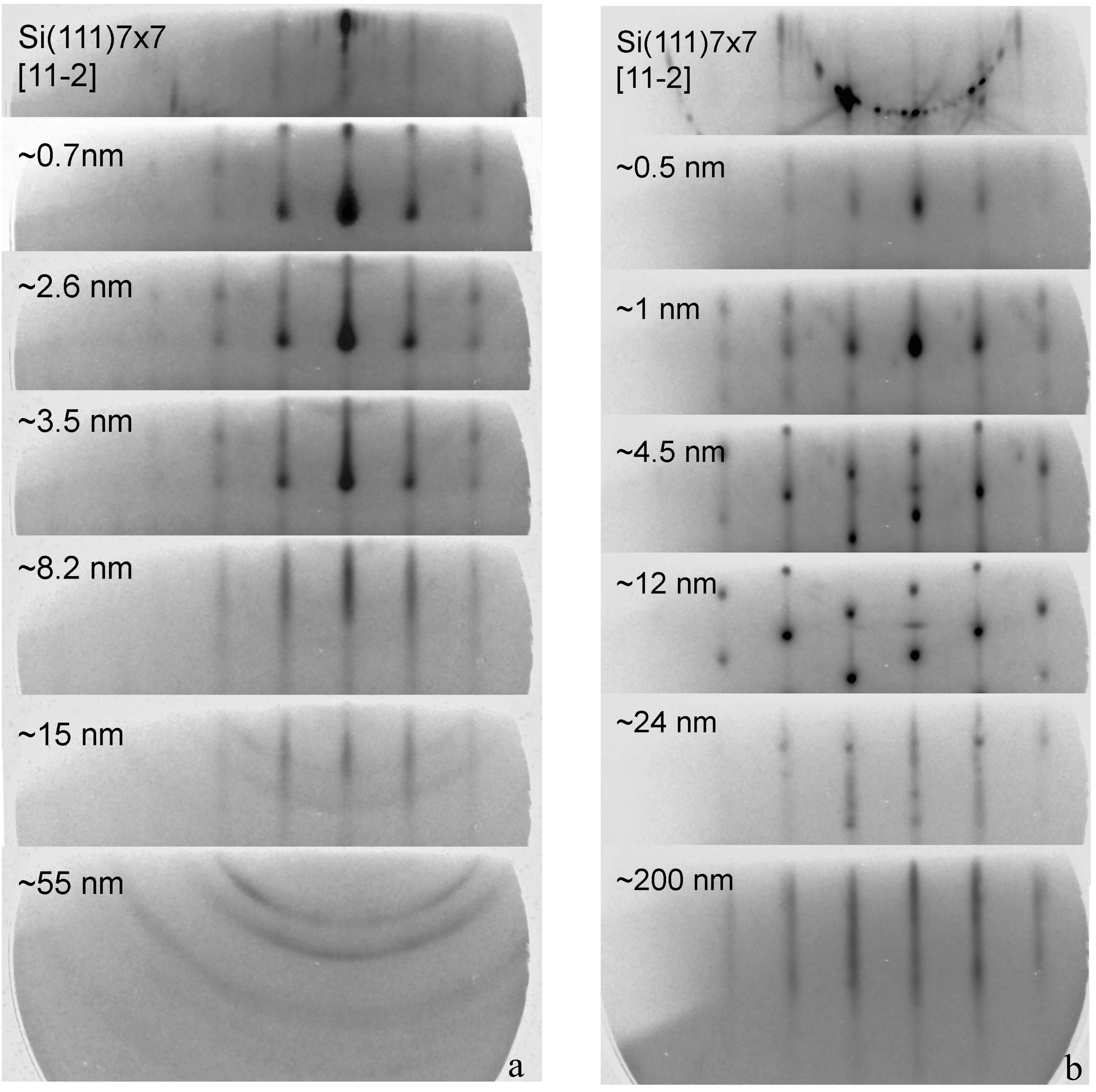

Fig.3. Evolution of RHEED on total thickness Mn_5Ge_3 film with:
a) single layer of Mn_5Ge_3; b) two buffer layers of nonstoichiometric Mn_5Ge_3

Results and discussions

A single-crystal film with an island morphology is formed at the initial deposition stages of a single-layer Mn_5Ge_3 film on Si(111)7×7 at a temperature of 390 °C. The film acquires a smoother surface at 6 nm thickness, while the crystal structure is transformed to polycrystalline at 15 nm the layer thickness (Fig. 3a).

The single-crystal Mn_5Ge_3 film with 26 nm thickness was formed after deposition of 3 nm $Mn_{[5-0.3]}Ge_3$ buffer layer on Si(111)7×7 at a temperature of 390 °C. However, a textured polycrystal begins to form with further deposition (Fig. 4a). AFM shows (Fig. 4b) two structure types: flat plates and islands. We suppose that diffraction streaks are related to flat aries but rings to islands.

The film of stoichiometric Mn_5Ge_3 grows with a single-crystal structure up to 200 nm after deposition of two buffer layers in succession with stoichiometry $Mn_{[5-0.3]}Ge_3$ and $Mn_{[5-0.15]}Ge_3$ and with 5 and 12 nm thicknesses, respectively. Fig. 3b shows the RHEED evolution patterns of the 200 nm thick Mn_5Ge_3 film obtained with two buffer layers.