MBE growth of Ge-doped PbSe ferroelectric Rashba semiconductor

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Ferroelectric Rashba semiconductors (FERSC) are a new class of multifunctional materials combining Rashba physics and ferroelectricity, hence, promising for semiconductor spintronics [1-2]. Although vast variety of materials have been theoretically predicted as FERSC, the experimental realization is, however, still limited to a few (mainly Telluride) compounds: GeTe [3], PbGeTe [4], SnTe [5]. Hereby we report low temperature epitaxial growth of a new ferroelectric Rashba semiconductor $Pb_{1-x}Ge_xSe$, thus providing a new material system for FERSC.

High-quality epitaxial films of $Pb_{1-x}Ge_xSe$ were grown by molecular beam epitaxy (MBE) on (111)-oriented BaF_2 substrates with 1µm PbSe buffer layers using elemental sources of PbSe and GeSe. To ensure Ge incorporation in the host material, a very low growth temperature is required to suppress GeSe reveaporation. Despite the remarkably low-temperature growth window, which is more than 100°C below the standard growth temperature of PbSe-based compounds, the epilayers of $Pb_{1-x}Ge_xSe$ demonstrate high quality pseudomorphic layer-by-layer 2D growth and atomically smooth surfaces exhibiting only monoatomic steps (Fig. 1). Ge incorporation in PbSe is extremely temperature-dependent and it saturates at lower growth temperatures below 160°C (Fig. 2,a). Due to Ge incorporation, the cubic rock-sault PbSe lattice undergoes a ferroelectric lattice distortion below the ferroelectric Curie temperature T_C., that is determined by the observation of a resistivity anomaly at the T_C.

The effect of Ge incorporation on the band structure of $Pb_{1-x}Ge_xSe$ quantum wells was determined by angle resolved photoemission spectroscopy (ARPES) performed at the SOLARIS Synchrotron with the samples transported in a battery operated vacuum suitcase. The ARPES measurements reveal a temperature-dependent ferroelectric Rashba spin splitting in the ferroelectric phase below the T_C (Fig.2.b) with a very large Rashba coupling constant. This makes the system very promising for spintronic device applications.

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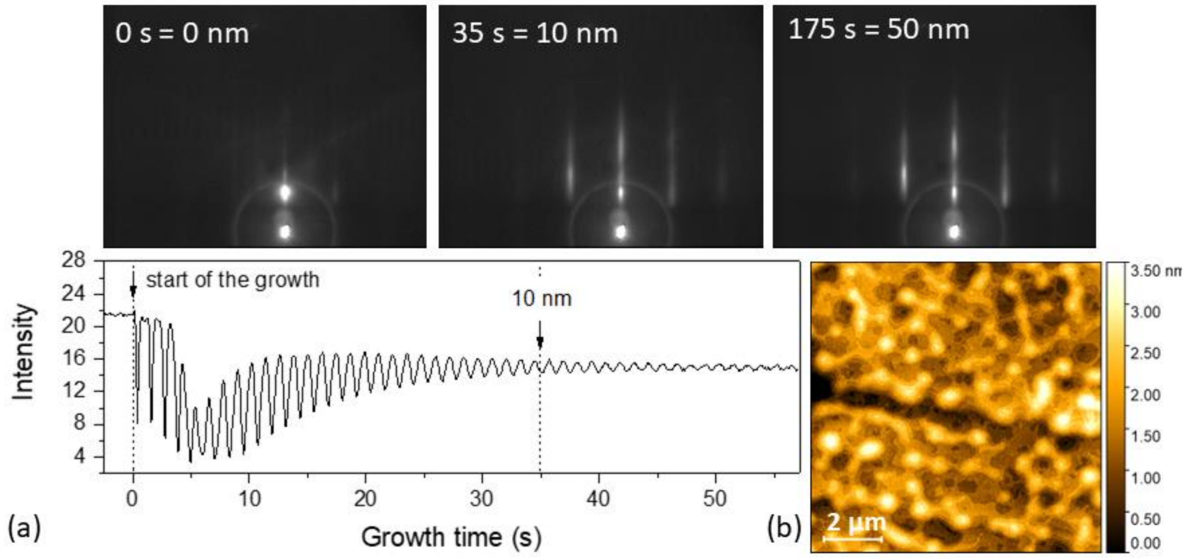

Fig. 1: Low-temperature high-quality epitaxial growth of $Pb_{1-x}Ge_xSe$: (a) RHEED intensity oscillations, signifying layer-by-layer growth and selected RHEED patterns, evidencing the pseudomorphic 2D growth of $Pb_{1-x}Ge_xSe$. (b) AFM image of 50nm – thick $Pb_{1-x}Ge_xSe$, showing atomically smooth surface.

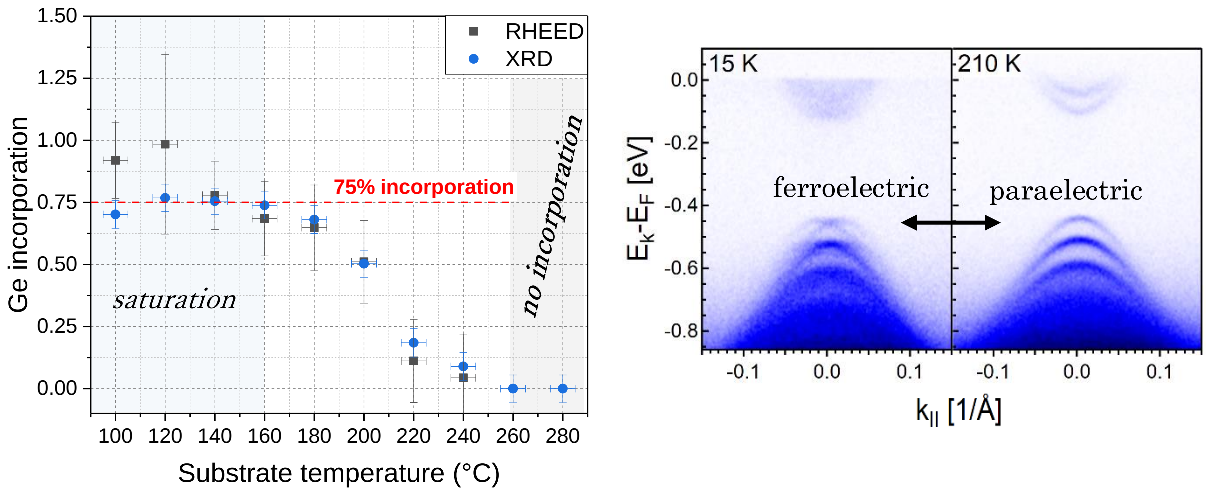

Fig. 2: (a) Ge incorporation in PbSe vs temperature, as determined from RHEED intensity oscillations and x-ray diffraction patterns. (b) Demonstration of ferroelectric-driven Rahsba effect in 10 nm – thick $Pb_{1-x}Ge_xSe$ by temperature-dependent angle resolved photoemission spectroscopy recorded along the M−K direction at a photon energy hν = 18 eV at the URANOS beamline of SOLARIS.