Atomic steps at cleaved (001) surface of bulk $Pb_{1-x}Sn_xSe$ topological crystalline insulator crystals

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$Pb_{1-x}Sn_xSe$ is a IV-VI semiconductor substitutional solid solution exhibiting composition and temperature controlled band inversion accompanied by the transition to topological crystalline insulator (TCI) state [1]. For the composition range x=0-0.4 $Pb_{1-x}Sn_xSe$ bulk crystals grow in the rock-salt lattice and cleave along (001) crystal planes thus providing an easy and versatile method for preparing atomically clean and flat surfaces. This is critical for angle-resoled photoemission (ARPES) and scanning tunnelling microscopy and spectroscopy (STM/STS) studies of topological states [1,2]. Recently, new one-dimensional topological electronic states have been discovered by STM/STS technique to reside along the atomic [010] step edges at the (001) crystal surface [2]. These topological states are observed only for crystals in the TCI phase with step height equal to the odd multiple of one monolayer thickness. No such states are found for "even" atomic steps or atomically flat regions of the surface [2]. These experimental observations are explained by a theoretical model identifying the "odd" steps as electronic domain walls [2].

In this work, we apply the atomic force microscopy (AFM) method to analyse the atomic-scale morphology of freshly cleaved surface of bulk $Pb_{1-x}Sn_xSe$ crystals grown by self-selecting vapour growth method in the entire rock-salt composition range. The AFM data are supplemented by crystal structure characterisation (XRD) and chemical homogeneity (SEM/EDX) analysis.

We observe atomically flat stripe-like terraces of typical area 1-20 μm^2 (Fig. 1) separated by atomic steps of the height varying from 0.3 nm (mono-atomic steps) to 2-3 nm. We studied the stability of the (001) surface under normal conditions (in the air). Remarkably, the atomic steps at the surface remain unchanged over days. We noticed, that the influence of air is related to chemical activity of Sn and appears as "nano-bubbles" (presumably of oxidized material) growing on terraces in timescale of days for x=0 but only minutes for crystals with x=0.3.

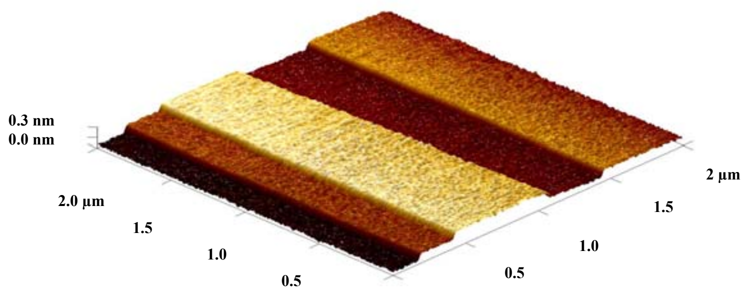

Fig. 1 AFM image of atomic steps at cleaved (001) surface of $Pb_{0.76}Sn_{0.24}Se$ crystal with 2 µm × 2 µm scan area.

[1] P. Dziawa, B.J. Kowalski, K. Dybko et al., Nat. Mat. **11**, 1023 (2012).
[2] P. Sessi, D. Di Sante, A. Szczerbakow et al., Science **354** (6317), 1269 (2016).

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