Selectively oriented crystalline growth of Mn_3Sn on $Al_2O_3(0001)$ using molecular beam epitaxy

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Kagome antiferromagnet Mn_3Sn has garnered attention due to the presence of interesting properties such as anomalous hall effect below 420K [1], Nernst effects, and presence of exchange bias [2] . Until now, most thin film growths have been conducted by using sputter deposition or by cleaving. Recently, Higo *et al.* reported perpendicular full switching of the Mn_3Sn device which was grown using molecular beam epitaxy on a MgO (110) substrate having a thin W buffer layer. The grown film had a $(01\bar{1}0)$ orientation and a perpendicular magnetic anisotropy which was attributed to a tensile strain of 0.25% in the $[21\bar{1}0]$ direction enabling 100% switching of the perpendicularly oriented magnetic octupole [3]. This result indicates that the orientation and possible strain of the film can be key for film transport properties, and therefore it is of great interest to explore how one can achieve different crystalline film orientations of Mn_3Sn.

In this talk, we demonstrate the synthesis of crystalline Mn_3Sn on Al_2O_3 (0001) without a buffer layer using molecular beam epitaxy. The samples were deposited at two different temperatures T_h (500 ± 9 °C) and T_l (416 ± 9 °C) with Mn: Sn flux ratio of 3.2:1 for 90 minutes. Our analysis indicates that for the two temperatures, the resulting orientations of the films are different, with the T_h sample being predominantly *c*-oriented and T_l sample being 43% *a*-oriented, but in our recent template growth method at room temperature, we achieved an 82% *a*-oriented film. In both cases, the reflection high energy electron diffraction patterns were streaky indicating a crystalline film, and the cross-sectional scanning tunneling electron microscopy gave an insight into the morphology of the samples. In both cases, the sample are discontiguous with a 3D morphology for the T_h - grown sample and quasi-2D morphology for the T_l - grown sample. Our recent template-grown samples are contiguous and show streaky RHEED patterns throughout the growth. Orientation relationships between the Mn_3Sn films and the sapphire substrates are determined from *in-plane* and *out-of-plane* measurements. The composition of the samples, the strain effects, and the crystalline structures will be discussed in detail. Furthermore, we are in the process of doing STM measurements on the samples and performing theoretical calculations.

[1] Z. Zhao, Q. Guo, F. Chen, K. Zhang, and Y. Jiang. *Physica B: Condensed Matter*, **604,** 412692 (2021).

[2] X.F. Zhou, X.Z. Chen, Y.F. You, L.Y. Liao, H. Bai, R.Q. Zhang, Y.J. Zhou, H.Q. Wu, C. Song, and F. Pan, *Phys. Rev. Applied* **14,** 054037 (2020).

[3] T. Higo, K. Kondou, T. Nomoto, M. Shiga, S. Sakamoto, X. Chen, D.N.-Hamane, R. Arita, Y. Otani, S. Miwa and S. Nakatsuji, *Nature* **607**, 474-479 (2022).

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Supplementary Pages

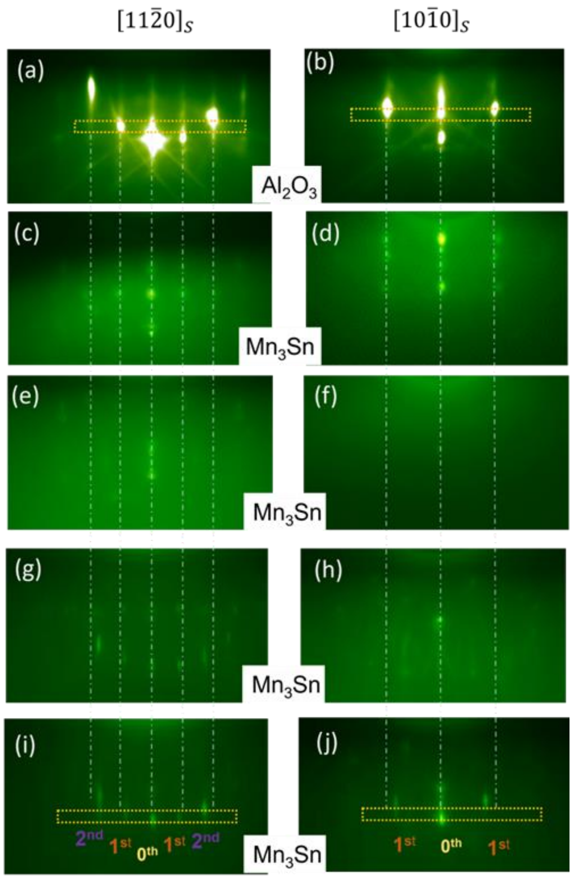

Figure 1: RHEED patterns of Al_2O_3 and growth of Mn_3Sn for sample A grown at T_h; (a-b) annealed Al_2O_3; (c-d) immediately after opening the shutter; (e-f) after 90 mins of Mn_3Sn growth; (g-h) Mn_3Sn next day at 300 K; (i-j) Mn_3Sn after 5 days at 300 K.

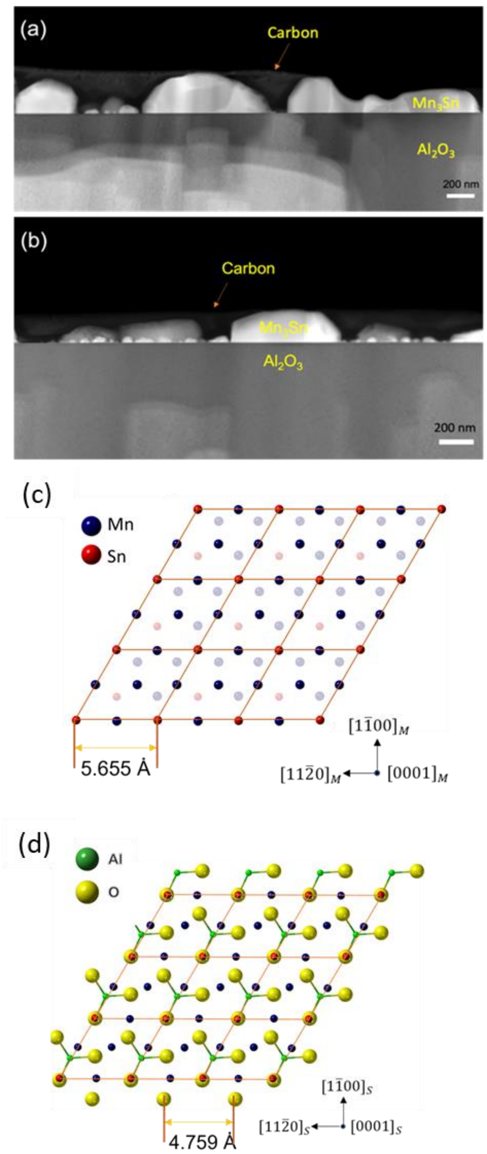

Figure 2: (a)-(b) STEM images taken at a high-angle annular dark field (HAADF) for sample A (grown at T_h); (c) Top view of the 2D crystal for sample A. The faded atoms indicate the z = ½ position. The orange lines indicate the unit cells of Mn_3Sn; (d) The overlay of Mn_3Sn on *c*-(0001) Al_2O_3 is shown for sample A.

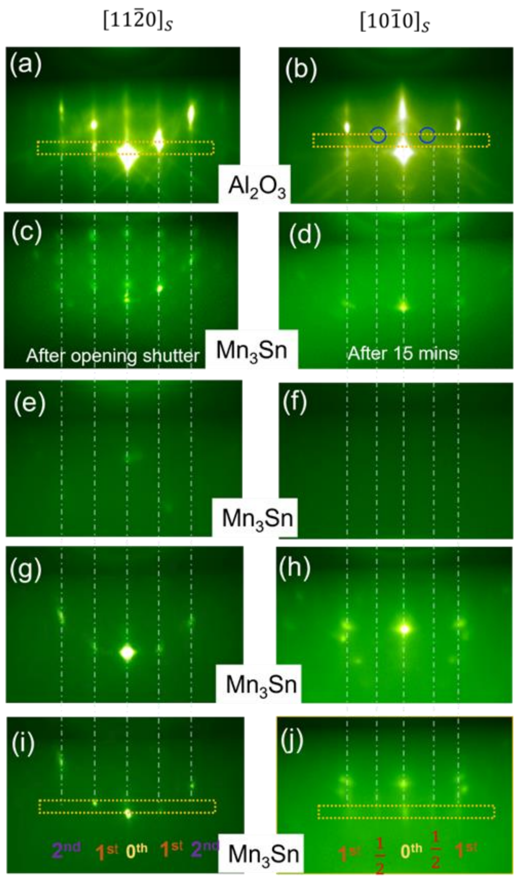

Figure 3: RHEED patterns of Al_2O_3 and growth of Mn_3Sn for sample B grown at T_l; (a-b) annealed Al_2O_3; (c) immediately after opening Mn and Sn shutter simultaneously; (d) after 15 mins of growth; (e-f) after 90 mins of growth; (g-h) Mn_3Sn next day at 300 K; (i-j) Mn_3Sn after 2 days at 300 K.

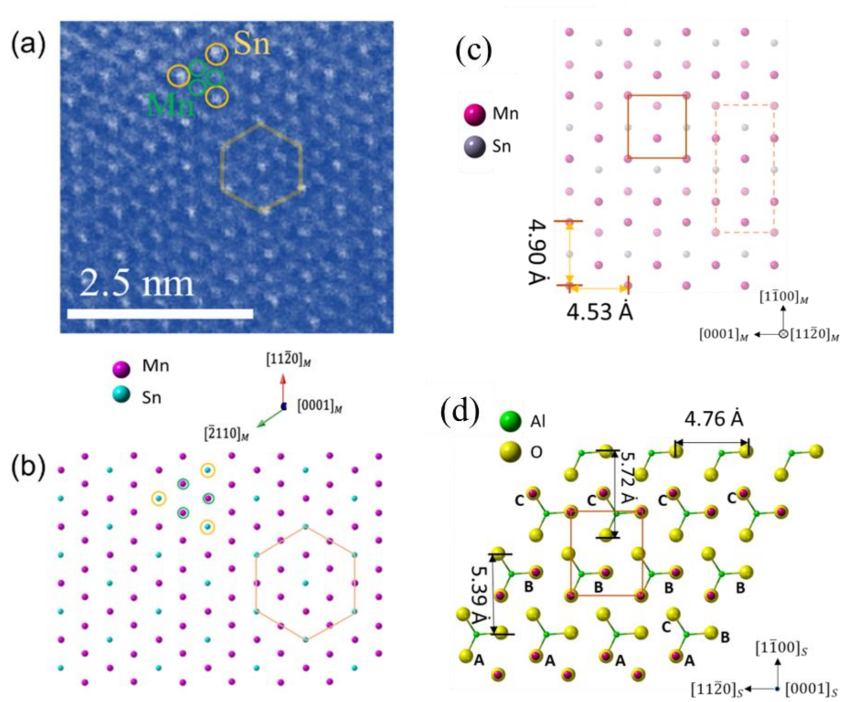

Figure 4: (a) Lattice imaging for sample B; (b) model showing the corresponding Mn_3Sn *c*-plane lattice; (c) top view of the 2-D crystal model of the *a*-plane oriented sample and (d) the pseudomorphic overlay of Mn_3Sn on *c*-(0001) Al_2O_3.