Investigating the Influence of Bismuth Surfactant on InSb Thin Films for Mid-Infrared Detection Applications

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Indium antimonide (InSb) possesses a narrow direct bandgap (0.17eV at 300K), facilitating efficient absorption and conversion of infrared photons in the mid-wave infrared (MWIR) spectrum. Consequently, InSb detectors demonstrate high sensitivity in thermal imaging, spectroscopy, and astronomical observation [1–5]. Recently, there has been notable interest in employing bismuth as a surfactant during the epitaxial growth of many III-V material systems [6,7]. A very low bismuth flux can modify the ad-layer surface and eventually desorb, leading to improved surface morphologies across multiple materials [6–8]. However, no studies on Bi surfactancy have been conducted on MBE-grown InSb thin films [6, 7, 9]. This work aims to document the effects of Bi surfactancy on InSb growth across a range of temperatures. We have recently shown that the Bi surfactant can substantially modify the morphology of GaSb thin films over a broad spectrum of growth temperatures. Given the significance of surface morphology control in multilayer epitaxial growth, especially those that require high-quality InSb layers, understanding its influence is crucial. Additionally, the systematic characterization of homoepitaxial InSb surfaces holds value for the MBE community.

Two series of homoepitaxial InSb(100) thin films are grown via molecular beam epitaxy (MBE) on an InSb(100) substrate over a range of growth temperatures. All other growth parameters remain identical. The first set serves as a control, while the second are grown under Bi surfactancy. Surface characterization is conducted using atomic force microscopy (AFM), scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (EDS) to analyze large features and elemental distribution. Raman spectroscopy and variable-angle spectroscopic ellipsometry (VASE) are employed to detect alterations in lattice and optical properties induced by the surfactant. Finally, high-resolution X-ray diffraction (HRXRD) is performed to detect any potential Bi incorporation. This study seeks to assess the effects of Bi surfactancy on the surface morphology and material properties of InSb thin films, potentially contributing to the advancement of next-generation MWIR detectors with improved performance for diverse applications.

References

[1] C. Downs and T. E. Vandervelde, "Progress in Infrared Photodetectors Since 2000," *Sensors*, vol. 13, pp. 5054–5098, Apr. 2013. Number: 4 Publisher: Multidisciplinary Digital Publishing Institute.

[2] W. K. Liu, W. T. Yuen, and R. A. Stradling, "Preparation of InSb substrates for molecular beam epitaxy," *Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures Processing, Measurement, and Phenomena*, vol. 13, pp. 1539–1545, July 1995.

[3] A. J. Noreika, M. H. Francombe, and C. E. C. Wood, "Growth of Sb and InSb by molecular-beam epitaxy," *Journal of Applied Physics*, vol. 52, pp. 7416–7420, Dec. 1981.

[4] S. Massidda, A. Continenza, A. J. Freeman, T. M. de Pascale, F. Meloni, and M. Serra, "Structural and electronic properties of narrow-band-gap semiconductors: InP, InAs, and InSb," *Physical Review B*, vol. 41, pp. 12079–12085, June 1990. Publisher: American Physical Society.

[5] Y. Song, Y. Gu, J. Shao, and S. Wang, "Dilute Bismides for Mid-IR Applications," in *Bismuth-Containing Compounds* (H. Li and Z. M. Wang, eds.), Springer Series in Materials Science, pp. 1–27, New York, NY: Springer, 2013.

[6] D. Kandel and E. Kaxiras, "The Surfactant Effect in Semiconductor Thin-Film Growth," vol. 54, pp. 219–262, 2000. Book Title: Solid State Physics ISBN: 9780126077544 Publisher: Elsevier.

[7] J. M. Millunchick and C. R. Tait, "Surface Mediated Growth of Dilute Bismides," in *Bismuth-Containing Alloys and Nanostructures* (S. Wang and P. Lu, eds.), Springer Series in Materials Science, pp. 201–214, Singapore: Springer, 2019.

[8] J. Massies and N. Grandjean, "Surfactant effect on the surface diffusion length in epitaxial growth," *Physical Review B*, vol. 48, pp. 8502–8505, Sept. 1993. Publisher: American Physical Society.

[9] S. Wang and P. Lu, eds., *Bismuth-Containing Alloys and Nanostructures*, vol. 285 of *Springer Series in Materials Science*. Singapore: Springer, 2019.