Molecular Beam Epitaxy Growth and Optical Quality of InAsBi

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Highly mismatched III-V materials, particularly dilute-nitrides and dilute-bismuthides, have received considerable attention lately due to their anomalously large bandgap reduction, which makes them interesting for mid-wavelength and long-wavelength infrared optoelectronics. For device applications, high optical-quality material is required; however, the introduction of nitrogen or bismuth typically degrades luminescence efficiency, although to differing degrees depending on the host matrix. While GaAs-based dilute-bismuthides have received much recent attention, InAs-based dilute-bismuthides have remained only lightly explored, despite their potential application to mid-infrared photodetectors and lasers. With careful optimization of the molecular beam epitaxial (MBE) growth conditions of InAsBi, we identified a growth regime free of phase segregation and droplet formation, resulting in significantly improved optical quality.

Samples were grown by solid-source MBE in an EPI Mod. Gen II system on n-type, sulfur doped (100) InAs substrates. Epitaxial layers of InAsBi, all nominally 150 nm thick, were grown under varying growth conditions. MBE growth parameters similar to those used to successfully grow GaAsBi [1], specifically: low substrate temperature (305-335^{o}C), high growth rate (0.9 μm/hr), and near stoichiometric V/III flux ratio (2.4-3.4 As_2/In BEP ratio) were investigated. Nomarski phase-contrast microscopy, atomic force microscopy, X-ray diffraction (XRD), and 77K photoluminescence (PL) were employed to characterize surface roughness, bismuth content, and optical quality. Notably, the optical quality as quantified by PL is a particularly strong function of growth temperature, even over a range where structural techniques such as XRD are unable to distinguish a difference.

Bismuth concentrations up to 5.25% were incorporated without forming bismuth droplets or sacrificing crystal quality, as qualified using Nomarski and XRD, respectively. Bismuth incorporation was independent of growth temperature from 305°C to 335°C, and for layers grown at 325°C, bismuth incorporation was found to be linear with bismuth flux for a fixed arsenic flux. Room temperature photoluminescence efficiency increased monotonically (~4x) with decreasing substrate temperature; however, ω-2θ XRD revealed no significant differences amongst the samples. Rutherford backscatter spectrometry (RBS) studies are underway to determine the interstitial bismuth concentration, and we expect that with further optimization the material quality can be improved to the level required for photonic device applications.

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[1] A.J. Ptak, R. France, D.A. Beaton, K. Alberi, J. Simon, A. Mascarenhas, and C.-S. Jiang, Journal of Crystal Growth **338**, 107-110 (2012).

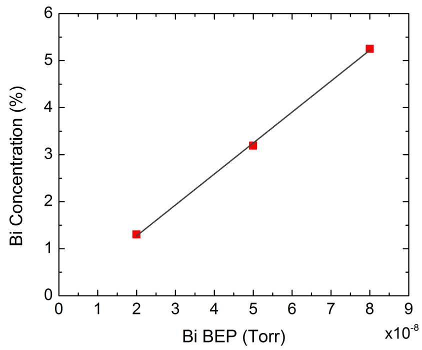

Figure 1. Bi concentration as a function of Bi BEP. All samples were grown at 325°C, at a growth rate of 0.9 µm/hr, and with an As_2/In BEP ratio of ~2.9. The highly linear dependence in this growth regime provides superior control over Bi incorporation.

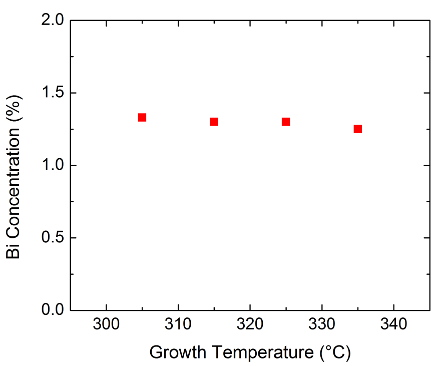

Figure 2. Bi concentration as a function of growth temperature. All samples were grown with a Bi BEP of 2E-8 Torr at a growth rate of 0.9 µm/hr and with an As_2/In BEP ratio of ~2.9. The weak temperature dependence signifies that the Bi sticking coefficient is near unity in this growth regime.

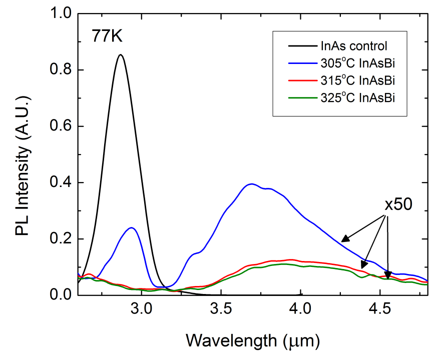

Figure 3. Photoluminescence (PL) intensity for samples grown at decreasing temperature. All samples were grown with a Bi BEP of 2E-8 Torr at a growth rate of 0.9 µm/hr and with an As_2/In BEP ratio of ~2.9, and all contain ~1.3% Bi. PL intensity increases at lower growth temperatures.

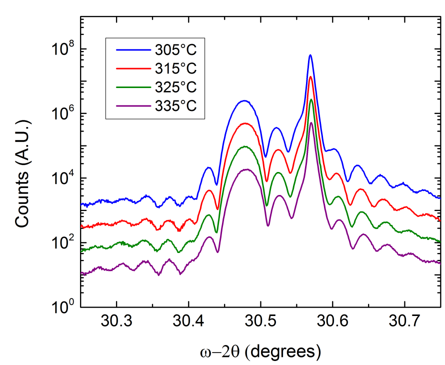

Figure 4. High resolution X-ray diffraction ω-2θ scans of the samples from Figure 3, offset vertically for clarity. The appearance of several Pendellösung signifies the presence of uniform films with smooth surfaces.