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Present status and future prospects of Bi-containing semiconductors

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Abstract: In this presentation, we will outline the progress of research on epitaxial growth of dilute bismide III–V alloys to obtain device-quality epilayers. In the early 80s, growth of InSbBi by molecular beam epitaxy (MBE) was reported by two groups, including the group of one of the authors (K.O.), with the aim of obtaining III–V alloys with the narrowest possible bandgap. In 1995, K.O. proposed that creation of GaInAsBi was a promising approach to realize a semiconductor laser whose wavelength does not change with ambient temperature variation, for application in wavelength-division-multiplexing (WDM) optical fiber communication. Since then, dilute bismide III–V alloys, such as GaAsBi, InAsBi, GaNAsBi, and GaInAsBi, have been created, and their properties have been studied by our group.

GaAsBi and InAsBi were initially created by metalorganic vapor phase epitaxy (MOVPE). The results of Rutherford back scattering (RBS) and Raman scattering spectroscopy as well as X-ray diffraction pattern of the epilayer revealed substitutional incorporation of Bi atoms in the As site of the zinc blende structure. In the case of InAsBi, the substitutional incorporation of Bi atoms in the As site was confirmed by fluorescence extended X-ray absorption fine structure (EXAFS). The temperature-insensitive nature of bandgap for GaAsBi was clarified by photoluminescence (PL) and photoreflectance (PR).

Because a low temperature growth is required to achieve incorporation of Bi atoms into the epilayer, insufficient decomposition of coexisting metalorganics in MOVPE is a concern in the expansion of the bismide III–V alloys to GaInAsBi quaternary alloys. The insufficient decomposition also causes carbon contamination in the epilayer. Therefore, we have focused on the MBE growth of bismide III–V alloys. While a segregated needle-like Bi-containing crystal was occasionally observed on the epilayer surface grown by MOVPE, it is advantageous that formation of such anomalous crystal is much suppressed because of easy desorption of Bi in MBE.

It is notable that luminescent GaAsBi can be obtained by low-temperatures MBE growth (<400 degree C), probably due to a surfactant-like effect of Bi atoms in MBE. Furthermore, GaNAsBi and InGaAsBi were successfully grown by MBE, resulting in the expansion of luminescence wavelength of GaAsBi-based alloys toward longer wavelength. Fabrication of multi-quantum-well structure of GaAs/GaAsBi with a smooth interface was demonstrated despite problems of Bi segregation.

As mentioned earlier, studies on GaAsBi-based alloys have passed the stage of realization of single crystalline epilayer. Currently, device-quality epilayers in terms of luminescence can be obtained under adequate growth conditions by MBE. In application of such alloys in a laser diode, control of epilayer defects remains a big challenge. Although much attention has been paid to enhance the qualities of GaAsBi-based alloys, the essence of growth conditions for

GaAsBi-based alloys is exactly the same as that of InSbBi growth in the early 80s. The conventional essence has been the low temperature growth (<400 degree C) with As (or Sb) flux adjustment in a limited range on the brink of As (or Sb) shortage on the growing surface. A novel growth technique is expected for further improvement in GaAsBi-based alloys.