

[IV-VI 族系混晶半導体の結晶成長およびフォトニックデバイスへの応用に関する研究]

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その後の研究成果報告

不純物添加混晶半導体を用いた積層構造デバイスを形成する場合、急峻な接合にするためには各界面において成分元素や不純物の拡散を抑制することが重要となる。例えば、ドーパントの拡散係数の値から推測して $\sim \mu m$ 厚のダイオードレーザの場合は無視できたとしても、数百Å厚の多層膜からなる量子井戸構造では無視できなくなる。したがって拡散抑制のためには積層膜の成長をできるだけ低温化する必要がある。これらの観点に立って(PbSn)Se系多層膜形成の前段階として、CaF₂基板上にn-Pb_{0.94}Sn_{0.06}Se/p-PbSe二層膜を形成し、成長温度の低温化、それに伴う結晶性および表面モフォロジーの変化、界面における不純物の拡散等について検討を行った。成果は14th International Vacuum Congress, 31Aug. 4Sept. 1998(Birmingham, UK)で発表、Thin Solid Filmsに投稿中である。概要を以下に示す。

[Undoped p-PbSe layers were epitaxially grown on CaF₂(111) substrates at 485°C, which had good crystalline quality with smooth surface morphology as reported previously, For the preparation of double layers, Pb_{0.94}Sn_{0.06}Se(LTS) layers could be epitaxially grown on top of PbSe layers at various growth temperatures ranging from 485°C to 200°C. The relations between RHEED patterns and the growth temperature indicated that epitaxy of LTS(111) can be maintained even at 200°C, although RHEED patterns vary from streaky to more spotty when the growth temperature is further reduced down to 200°C. This epitaxial temperature is considerably lower as compared to that in the direct growth on CaF₂. In the results, epitaxial temperature of LTS could be reduced by growing on the PbSe/CaF₂. This may be attributed to the fact that the lattice mismatch between LTS and PbSe is much smaller than that between LTS and CaF₂, and the thermal mismatch is negligible small for both these material combinations. PbSe can behave as a virtual substrate available for subsequent growth of LTS. The X-ray rocking curves of the Bragg(222) reflection for the upper LTS layers were measured and the FWHM values were evaluated. The dependence of FWHM values for Bi doped layers on the growth temperature indicated that the FWHM tended to increase when the growth temperature was reduced and especially for LTS layers grown at below 300°C, the FWHM became larger. The results suggest that LTS is desired to grow at above $\sim 300^\circ\text{C}$, because the increase of FWHM corresponds to deterioration of crystalline quality in epitaxial layers. PbSe layer was undoped and p-type with hole carrier concentration of the order of 10^{17}cm^{-3} at 77K, whereas LTS layer doped with Bi or Bi₂Se₃ became n-type by adjusting the dopant flux and the electron carrier concentration was estimated at the order of 10^{18}cm^{-3} and the crystalline quality of LTS layer doped with Bi₂Se₃ is not so different from that with Bi in the case of concentration level $\sim 10^{18}\text{cm}^{-3}$. From the SIMS analysis, the deviation from the abrupt profile of Bi concentration was observed at the interface between LTS and PbSe. This suggests possible diffusion of Bi from LTS side into PbSe side. The depth from the interface to PbSe side where Bi concentration was reduced by one order of magnitude, was estimated at $<500\text{\AA}$ in the case of doping time of 5 min. and the growth temperature of 300 \sim 400°C and tended to increase as the growth temperature increased. The depth for layers doped with Bi₂Se₃ was found to be somewhat smaller than that for layers doped with Bi. Diffusion coefficient was roughly estimated from the solution of diffusion equation for the constant concentration, resulting in the value of the order of $10^{-15}\text{cm}^2/\text{sec}$ in the case of Bi diffusion from LTS($n \sim 10^{18}\text{cm}^{-3}$) into undoped PbSe($p \sim 10^{17}\text{cm}^{-3}$) at 300 \sim 400°C. This value is quite smaller than that of junction diffusion in p-n junction with nonstoichiometric gradients for Pb-salts. Therefore, the use of impurity doping with good carrier control, would be preferable to that of nonstoichiometric gradient for junction device growth. Electrical characterisation by C-V properties is in progress.]