Growth-Temperature Effect on Group-V Compositions in 'W' Structured GaAsSb/InGaAs/GaAsP Quantum Wells

Zon[1]*, Chao-Chia Cheng[2], Chun-Nien Liu[1], Jen-Inn Chyi[3] and Charles W. Tu[1]*
[1]Department of Electrical Engineering, National Chung Hsing University, Taichung, Taiwan
[2] Department of Physics, National Central University, Chung-Li, Taiwan
[3] Department of Electrical Engineering, National Central University, Chung-Li, Taiwan
*E-mails: ctu@ucsd.edu, zon@dragon.nchu.edu.tw

The display cutout area, "notch" or "Dynamic Island", of an iPhone is located at the top of the display and houses the front-facing camera, vertical-cavity surface-emitting lasers (VCSELs), and detectors for Face ID. These VCSELs use top and bottom AlAs/GaAs Distributed Bragg Reflectors (DBRs) as the vertical cavity, and the emission wavelength is limited to 980 nm, which cannot penetrate the display, and hence the "notch". It is desirable, however, to utilize the whole display, edge to edge, if the wavelength can be 1380 nm. Furthermore, the minimum permissible exposure for eye safety is about 500 times higher at 1380 nm than at 980 nm. Therefore, many groups are pursuing long-wavelength emission on GaAs substrates for these two reasons. There have been several approaches. One is wafer bonding of InP-based lasers and GaAs-based DBRs, which is a more complicated process than simpler epitaxy. Other approaches are dilute nitrides and self-assembled InAs quantum dots, but they suffer from low output power due to material defects and small active volumes, respectively. This paper studies another approach: type-II InGaAs/GaAsSb 'W'-quantum wells (QWs) with GaAsP strain compensating layers grown on GaAs (001) substrates by MBE. The schematic band diagrams are shown in **Fig. 1**.

The control of group V-compositions in ternary and quaternary compounds, such as GaAsP, InAsP, GaAsSb, InAsSb, InGaAsP, and InGaAsSb, is a significant challenge. The growth temperature was varied from 450 to 540ºC while other growth parameters were kept the same. The designed QW-thicknesses and material compositions (Sb, In, and P%) are 15 nm-$GaAs_{0.9}Sb_{0.1}$, 3 nm-$In_{0.3}Ga_{0.7}As$, and 15 nm-$GaAs_{0.75}P_{0.25}$, respectively. **Fig. 2** shows the x-ray rocking curves (XRCs) and simulations of 'W'-QWs grown at five different growth temperatures. The extracted results from XRC analysis prove that the group-V compositions (As, Sb) and (As, P) are varied as a function of growth temperature. The phosphorus composition in GaAsP increased at growth temperatures >500°C. At higher temperatures, the group-V materials desorb readily and compete with each other during the growth. The desorption affects the growth rate and, consequently, QW thickness. Unlike the P incorporation behavior, the Sb composition in GaAsSb decreases with higher growth temperature. This can be attributed to the lower sticking coefficient of Sb at higher temperatures. The different incorporation behaviors of P and Sb were numerically extracted as shown in **Fig. 3**. Photoluminescence (PL) emissions are observed from shorter to longer wavelengths by increasing Sb incorporation. The very low Sb composition creates type I-GaAsSb/InGaAs QWs, resulting in stronger PL at shorter wavelengths, as shown in **Fig. 4**.

In summary, the different incorporation behaviors of group-V materials in GaAsSb/InGaAs/GaAsP 'W'-QW affected by the growth temperature are experimentally investigated. XRC determines the material compositions, QW thicknesses, and crystalline quality. The emitted PL characteristics are in good agreement with XRC. The optimum growth temperature range of 450-500°C for 'W'-QW is revealed to achieve better Sb incorporation and extend the PL emission wavelength.

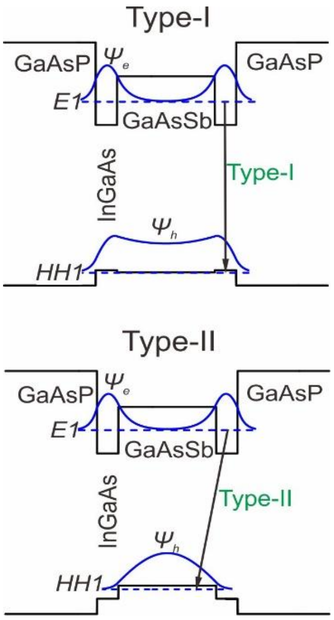

Fig. 1. Schematic band-alignments and wavefunction distributions of type-I (lower Sb%) and type-II (higher Sb%) GaAsSb/InGaAs/GaAsP 'W'-QWs.

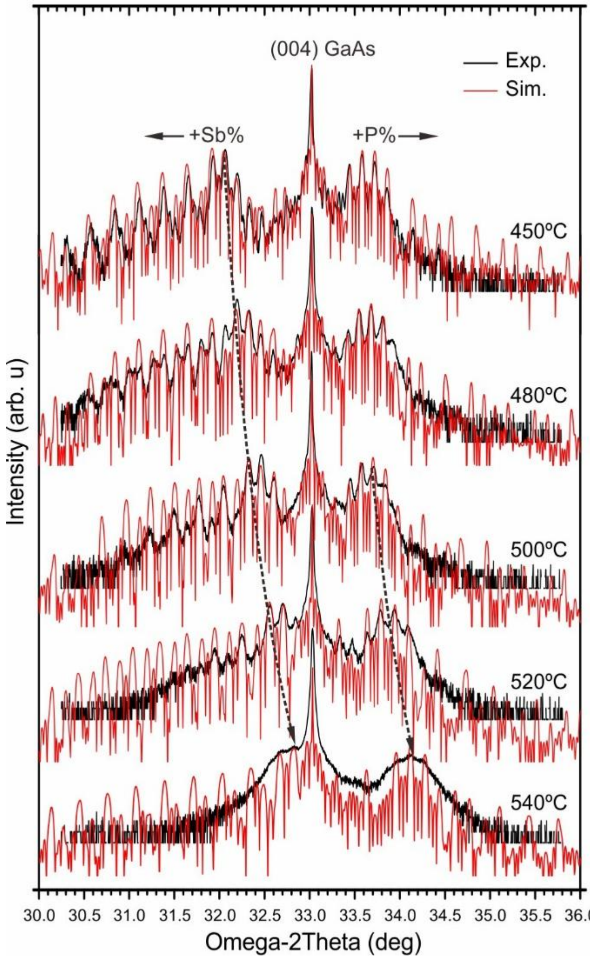

Fig. 2. X-ray rocking curves with simulations of 'W'QWs grown at different temperatures.

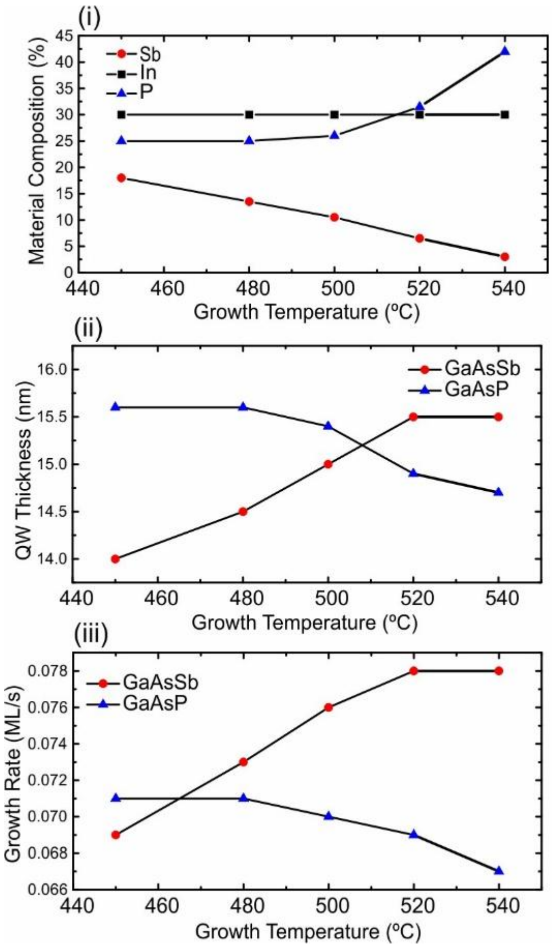

Fig. 3. (i-iii) The group-V material incorporation behaviors on the 'W'-QW parameters.

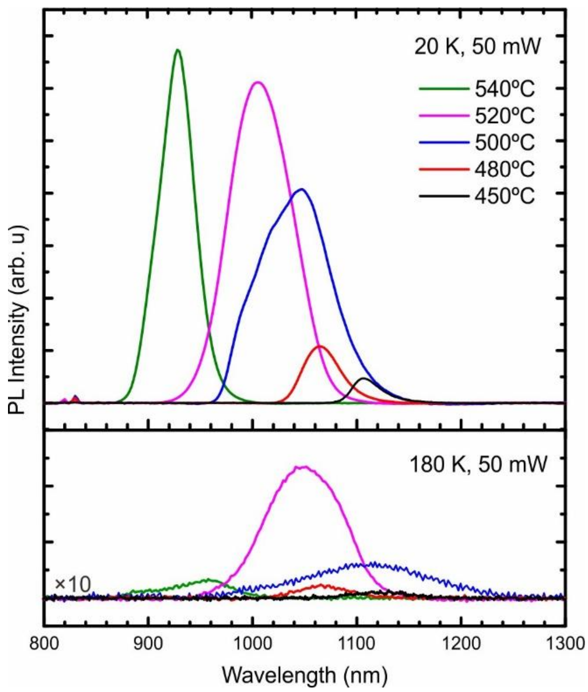

Fig. 4. Low- and high-temperature PL emissions of 'W'-QW grown at different temperatures.