Polarization Control in Nitride-Based Semiconductors

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AlGaInN-based semiconductors are the most promising materials for ultraviolet laser diodes and blue/green light emitting diodes because of their direct wide bandgap ranging from 1.9 to 6.2 eV. Currently high-quality nitride materials are obtained by epitaxial growth on sapphire substrates using low-temperature-deposited layers as nucleation layers.[1] In this case, the crystals grow with a wurtzite structure oriented along (0001) direction. Since the nitrides have large piezoelectric constants and spontaneous polarization, large internal fields are generated in strained heterostructures, such as strained quantum wells (QWs). GaInN/GaN QWs are commonly used as active layers in light emitting devices, and many theoretical and experimental reports show the existence of piezoelectric fields in the strained GaInN QWs.[2-4] These fields lower the transition probability of injected carriers due to the spatial separation between electron and hole wavefunctions, especially the case of higher InN molar fraction. Therefore, control of the polarization fields in GaInN QWs is one of the most important issues to realize green laser diodes and red light emitting diodes.

We have theoretically investigated the growth orientation dependence of the induced piezoelectric fields in wurtzite $Ga_{0.9}In_{0.1}N$ QWs as shown in Fig. 1. We found that (0001) orientation has the largest piezoelectric field of 0.7 MV/cm along the growth direction. On the other hand, $(10\bar{1}0)$, $(11\bar{2}0)$ (90 ^{o} off from (0001)) and $(10\bar{1}2)$, $(11\bar{2}4)$ (around 39 ^{o} off from (0001)) have no piezoelectric field. We also calculated the growth orientation dependence of the transition probability in a 3 nm $Ga_{0.9}In_{0.1}N$/GaN QWs. The transition probabilities of the orientations with the off angles of 39 ^{o} and 90 ^{o} are more than 2 times higher than that of (0001). This is attributed to the larger overlap between the electron and hole wavefunctions due to no internal piezoelectric fields.

Our practical approach to establish the non-(0001) growth orientation is using the inclined facets, such as $(10\bar{1}1)$ (62 ^{o} off from (0001)), obtained during the lateral over growth. Our calculation result suggests that, in the $(10\bar{1}1)$ orientation, the piezoelectric field can be reduced to 40% and the transition probability can be still doubled in value, compared to the (0001) orientation. We have grown GaInN/GaN 5QWs on the $(10\bar{1}1)$ facets formed by the lateral over growth. A cross-sectional TEM image shown in Fig. 2 indicates that we have successfully grown the $(10\bar{1}1)$ -oriented GaInN/GaN QWs. We also obtained the electroluminescence from the QWs sandwiched by n- and p-layers, however, the efficiency was a few times lower than that of conventional (0001)-oriented QWs so far. The further optimizations of growth conditions including the formation of the inclined facets will be necessary.

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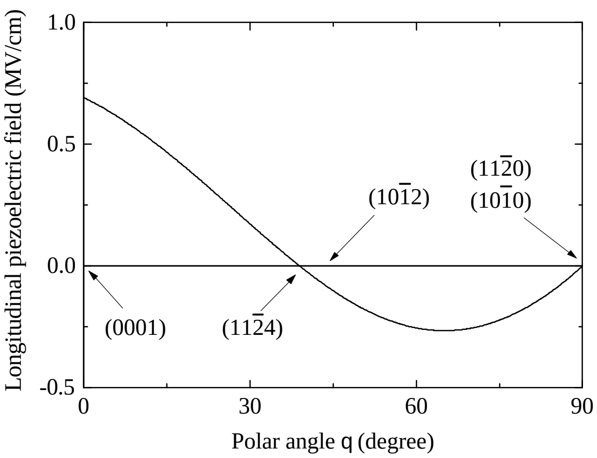

Fig.1 Orientation dependence of piezoelectric field along the growth direction in $Ga_{0.9}In_{0.1}N$/GaN QWs.

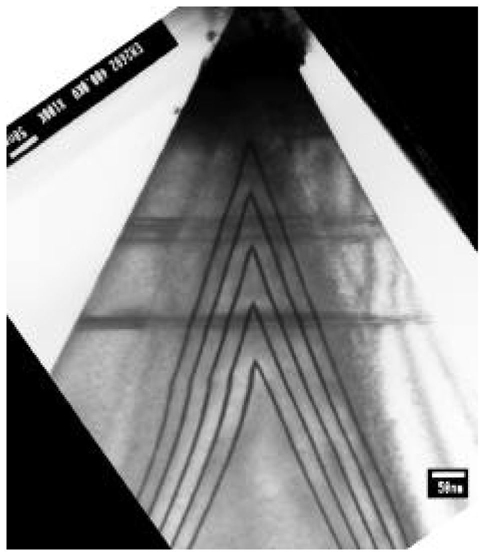

Fig.2 Cross-sectional TEM image of GaInN/GaN 5QWs on the inclined $(10\bar{1}1)$ facets.