Effectiveness of $In_{0.1}Ga_{0.9}As$ dislocation filters to reduce threading dislocation density

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Epitaxially grown semiconductor laser material on Si (001) with quantum dot (QD) active regions is important for lower cost optical interconnects. The projected QD laser lifetime is more than a million hours at 35 °C under continuous-wave (CW) operation [1]. The drastic reliability improvement is primarily due to the reduction of threading dislocation density (TDD) on the GaAs on Si buffer surface. Further reduction of TDD is needed for high temperature reliability and future integration with Si waveguides. Here, we investigate the effectiveness of $In_{0.1}Ga_{0.9}As$ dislocation filter layers grown on GaAs with different TDD. We investigate the filtering mechanism and provide insights to further lowering of TDD while also reducing total epitaxial thickness.

To generate GaAs surfaces with different TDD, a GaAs buffer layer (Fig. 1a) was grown on low defect density GaP on Si templates from $NASP_{III/V}$, GmbH. Temperature cyclic annealing (TCA) was then performed with temperature ranging from 400 °C to either 700 °C or 735 °C, and 4, 8, or 12 cycles. The surface roughness of all 6 samples are similar, according to atomic force microscopy (AFM) measurements. 200 nm $In_{0.1}Ga_{0.9}As$ and 300 nm GaAs were then grown after TCA at 500 °C (Fig.1a). TDD was measured with electron channeling contrast imaging (ECCI) both before and after the growth of the filter layer. The results are summarized in Fig.1(c). Higher number of cycles reduced TDD with the effect being more prominent at lower maximum cycling temperature. The TDD is further reduced after the growth of the $In_{0.1}Ga_{0.9}As$ filter layer. The effectiveness of the filters, namely the percentage TDD reduction, on different TDD is shown in the inset of Fig.1(c). Although samples with maximum temperature of 700 °C have higher starting TDD, the filtering effectiveness is lower than the samples with maximum temperature of 735 °C. This implies that the filtering is facilitated not only by lateral motion of existing TDs, but also the formation of new glissile TDs as bridges between the existing TDs. The effect of initial GaAs thickness, filter layer structure, and relaxation asymmetry on the filtering effectiveness will be discussed.

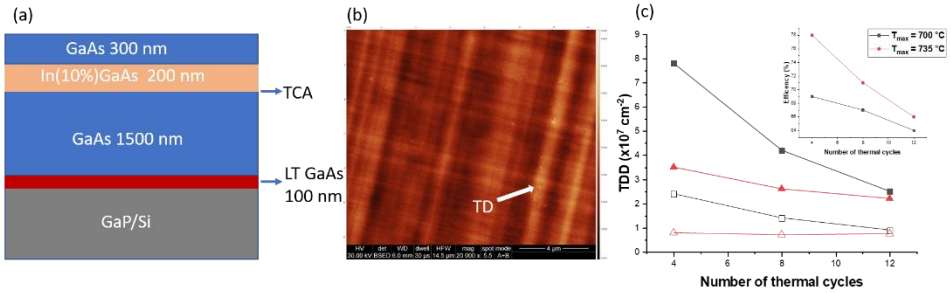

Figure 1: (a) Sample structure schematic. (b) Example ECCI image. (c) TDD measurement summary: (■) T_{max} = 700 °C, before filtering, (□) T_{max} = 700 °C, after filtering, (▲) T_{max} = 735°C, before filtering, (△) T_{max} = 735 °C, after filtering. Inset: Filtering efficiency as the percentage change of TDD.

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