Comprehensive Study of Photocarrier's Lifetime in Strain-Compensated InGaAs/InAlAs Superlattice on the Polar InP(111)B Substrates as a Function of the Design Parameters

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The growing range of terahertz (THz) frequency applications requires advanced THz sources and detectors with high sensitivity and broad bandwidth. The key objective is to develop a photoconductive material addressing a trade-off between photocarrier lifetime and mobility. InGaAs stands out as a unique material that can be excited by compact and cost-efficient femtosecond telecommunication lasers at 1550 nm. However, InGaAs faces challenges such as long photocarrier relaxation time and low resistivity. To address these issues, researchers have proposed utilizing InGaAs/InAlAs superlattices (SLs) on InP(100) substrates, doped with Be, Fe, Eu, or Rh, to enhance the resistivity of InGaAs layers sandwiched between two InAlAs barriers and shorten the relaxation time of photocarriers, at a cost of carriers mobility [1, 2]. InGaAs/InAlAs SLs grown on polar InP(111)B substrates have been recently proposed as a new material system for efficient THz generation, potentially having the performance of LT-GaAs, commonly used in conventional terahertz time-domain spectroscopy (TDS) systems, while being compatible with telecom 1550 nm femtosecond lasers [3].

The primary obstacle to realizing such superlattices has been the formidable challenge of growing them on (111)-oriented substrates, primarily due to the pronounced tendency for growth front roughening. Thanks to a recent breakthrough as reported [3], we now possess the capability to grow such SLs across a broad spectrum of design parameters, enabling the investigation of their impact on SLs properties. This encompasses variations in well and barrier thicknesses as well as their compositions. Modifying the latter enables the manipulation of strains within these structures, thereby embedding strong piezoelectric fields in the quantum wells and barriers in a controlled manner. Leveraging this effect to its fullest potential in photoconductive material design and during low-temperature epitaxial growth will facilitate the attainment of rapid photocarriers recombination, while preserving the high carrier mobility of InGaAs.

We present, for the first time, strain-compensated InGaAs/InAlAs superlattices (SLs) grown on stationary InP(111)B substrates by MBE. The strain is intentionally incorporated into each period of superlattice to use piezoelectric fields during the low-temperature growth time. Additionally, the zero-stress principle is applied to each InGaAs/InAlAs stack to avoid the formation of threading dislocations, which could lead to the relaxation of strained layers. The proposed unique methodology allows us to investigate the sub-picosecond photoexcited carrier dynamics as a function of a broad range of SL parameters and induced piezoelectric fields. Our analysis includes a detailed exploration of the InGaAs/InAlAs SL parameters and their correlation with the photoexcited carriers recombination times, sample's surface morphology, and structural properties of the interfaces in such strained superlattices.

References

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