Exploring Photoexcited Carrier Dynamics in Be-Doped Low-Temperature Grown InGaAs/InAlAs Strained-Balanced Superlattices on InP(001) for Terahertz Detection

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Over the last decade, terahertz time-domain spectroscopy (THz TDS) has transitioned from a scientific tool to a prospective technology for real-world applications, in particular, in the field of industrial non-destructive testing. Despite the recent advances in THz technology, current research endeavors focus on addressing the critical need for efficient and stable THz sources, as well as broadband and highly sensitive THz detectors operating at room temperature. This present study investigates the impact of design parameters on electrical and photoexcited carrier dynamics in a 30-period Be-doped low temperature (LT) InGaAs/InAlAs strain-balanced Superlattices (SLs) grown on InP(001) substrate. These SLs form the core of photoconductive antennas (PCAs) utilized as transmitters (Tx) and receivers (Rx) in the THz TDS systems driven by compact, stable, and cost-effective femtosecond fiber lasers operating at 1550 nm wavelength.

InGaAs semiconductors have the potential to be excited with such commercially available lasers. However, this material exhibits low resistivity and long photoexcited carrier lifetime. Recently, Be, Fe, and Rh-doped LT-InGaAs/InAlAs SLs grown by Molecular Beam Epitaxy (MBE) have emerged as promising candidates that have been proposed to enhance the resistivity and expand the spectral range [1, 2, 3]. Despite advances in such SLs, further improvements are necessary to achieve optimal performance levels. This requires developing a photoconductor with exceptional characteristics including high absorption coefficient, high dark resistivity, and high carrier mobility coupled with a sub-picosecond photoexcited carriers' lifetime. In short, these photoconductive materials should combine the advantages of the well-established LT-GaAs material and telecom wavelength compatibility to present a revolutionary prospect for THz applications. However, achieving these objectives simultaneously poses a challenge due to the inherent trade-off between carrier lifetime and carrier mobility in such materials, which must be carefully balanced. This work addresses the present lack of comprehensive studies investigating the influence of structural parameters on photoexcited carrier dynamics in such SLs.

In this study, we explore the unique capability of MBE to embed well-controlled lateral gradients of structure parameters across atomically smooth and defect-free 30-period Be-doped LT-InGaAs/InAlAs strain-balanced SLs grown at temperature 250°C with doping concentration of 4×10^{18} cm^{-3}. This is achieved by growing such SLs on stationary (i.e., not rotating) substrate and taking advantage of lateral variation in atomic fluxes arriving from effusion cells located at different azimuthal positions around the reactor. With this approach, we are able to measure photoexcited carrier dynamics in 30-period Be-doped LT-$In_xGa_{(1-x)}As/In_yAl_{(1-y)}As$ strain-balanced SLs across a broad range of structural parameters. Specifically, we study the effect of the SLs' key parameters, such as strain, quantum well and barrier compositions, and their widths on the photocarrier lifetime. A wide range of x composition varying from 0.5 to 0.72 and y composition varying from 0.34 to 0.58 is investigated. The thickness of wells and barriers studied are from 11.2 to 12.5 nm and from 7.5 to 8.4 nm, respectively.

To study and analyze sub-picosecond carrier dynamics, we developed a time-resolved differential reflection (DR) pump-probe spectroscopy system in our laboratory. The detailed finding on photoexcited carrier dynamics of such SLs will be demonstrated at the conference. These in-sights, derived from several growth parameters, will provide valuable guidance for further enhancing the performance of such SLs, paving the way for advanced portable THz pulsed spectroscopic and imaging systems.

References

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