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RECOMBINATION MECHANISMS IN GALLIUM ARSENIDE (GAAS) SEMICONDUCTORS

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Annotation: This paper explores the recombination mechanisms in III-V group semiconductors, focusing specifically on Gallium Arsenide (GaAs) and Indium Phosphide (InP). These materials are widely used in optoelectronic devices due to their direct bandgap and high electron mobility. The study discusses different types of recombination processes including radiative, non-radiative, and Auger recombination, and analyzes their dependence on factors such as temperature, doping level, and crystal defects. A comparative analysis between GaAs and InP is presented to highlight their performance in various applications such as LEDs, lasers, and high-efficiency solar cells. Understanding the recombination dynamics in these semiconductors is crucial for improving the efficiency and reliability of modern electronic and photonic devices.

Key words: Gallium Arsenide (GaAs), III-V semiconductors, recombination mechanisms, radiative recombination, non-radiative recombination, auger recombination, defects in semiconductors, direct bandgap materials, optoelectronic devices.

Semiconductor materials are widely used in modern electronics and optoelectronics. In particular, III-V group semiconductors such as Gallium Arsenide (GaAs) and Indium Phosphide (InP) are distinguished by their direct bandgap, high carrier mobility, and efficiency. These materials are primarily used in lasers, LEDs, solar cells, and high-speed electronic devices.

Gallium Arsenide (GaAs) is a III-V group AIII-BV compound semiconductor material with a metallic luster and a dark gray crystalline appearance. GaAs is a direct bandgap semiconductor with a bandgap energy of approximately 1.42 eV at 300 K, making it highly suitable for optoelectronic applications. Due to its high electron mobility (approximately 8500 $cm^2/V\cdot s$) and low dielectric loss, GaAs is widely used in infrared optics, optoelectronics, and microelectronics. Typically, GaAs crystals are doped with impurities that substitute gallium or arsenic atoms in the crystal lattice, thereby modifying the material's electrical characteristics. These dopants may occupy substitutional or interstitial lattice sites. The interaction between these impurities and intrinsic crystal defects significantly affects the overall electrical and optical properties of the material. Heavily silicon-doped GaAs crystals are employed in the manufacturing of injection lasers, LEDs, photocathodes, and microwave generators. In microelectronics, semi-insulating GaAs compounds such as GaAlAs are used as a base material. GaAs crystals are grown using various methods, including the Czochralski technique, zone melting, and vertical and horizontal directional solidification. In optical applications, high-purity, semi-insulating GaAs crystals are preferred. For instance, when low-power CO_2 lasers with wavelengths of 9.6–10.6 microns are used, GaAs serves as an alternative to zinc selenide (ZnSe) in the production of lenses and beam splitters.

In group III-V semiconductors, particularly Gallium Arsenide (GaAs), recombination processes are generally divided into three main types: radiative (light-emitting), non-radiative, and Auger recombination. Among them, radiative recombination is one of the most important, especially in optoelectronic devices (such as LEDs and laser diodes).

Radiative recombination is typically modeled using the Van Roosbroeck–Shockley approach, which takes into account the emission of a photon (quantum of light) as a result of recombination. Recent research has updated this model to address discrepancies between theoretical predictions and experimental results.

To determine the radiative recombination coefficient , the following integral is used:

$$B(T)=\frac{1}{n^2}\cdot\frac{1}{\pi^2\hbar^2c^2}\int_0^\infty n_{ref}^2\cdot E^2\cdot\alpha_{BB}\cdot e^{-\frac{E}{k_BT}}dE$$

In this model, the temperature dependence of and the energy bandgap is neglected, since they vary slowly with temperature. This approach leads to a first-order approximation for the temperature dependence of the radiative lifetime , expressed as:

$$\tau=\frac{1}{\mathbf{B(T)\cdot N_{D/A}}}=\frac{C_rN_C(T)\cdot N_V(T)}{T}$$

Here, is the $\mathbf{N_{D/A}}$ donor/acceptor concentration, $N_C(T)$ and $N_V(T)$ are the temperature-dependent effective density of states for the conduction and valence bands, respectively. Using the parabolic band approximation, these densities are proportional to $T^{3/2}$.

For GaAs at temperatures below 300K, this approximation yields accurate results with an error less than 7%:

$$\tau=A_rT^2$$

For higher temperatures, a more accurate empirical model is expressed as:

$$\tau=A_r(1+52.39e^{-171.5m_eV/k_BT})T^2$$

These formulas provide a clear understanding of the temperature dependence of radiative recombination in GaAs, which is crucial for evaluating the performance and efficiency of semiconductor devices.

Conclusion. Recombination processes in gallium arsenide (GaAs) semiconductors play a critical role in determining the efficiency and performance of optoelectronic and microelectronic devices. The primary recombination mechanisms observed in GaAs are radiative recombination, non-radiative (Shockley–Read–Hall) recombination, and Auger recombination. Radiative recombination is highly efficient in GaAs due to its direct band gap structure, making it ideal for light-emitting applications such as laser diodes, LEDs, and photodetectors. Non-radiative recombination, caused by defects and impurities in the crystal lattice, leads to energy losses and reduced carrier lifetime. Auger recombination becomes significant at high carrier concentrations and is especially important in high-power devices, where it contributes to thermal losses and efficiency degradation.

References:

1. Sze, S. M., and Ng, K. K. (2006). Physics of Semiconductor Devices (3rd ed.). Wiley-Interscience.

2. Streetman, B. G., and Banerjee, S. (2015). Solid State Electronic Devices (7th ed.). Pearson.

3. Blakemore, J. S. (1982). Gallium Arsenide: Fundamental Properties and Use as a Semiconductor. Journal of Applied Physics, 53(10), R123-R181.

4. Adachi, S. (1992). Physical Properties of III–V Semiconductor Compounds. Wiley-Interscience.

5. Nelson, J. (2003). The Physics of Solar Cells. Imperial College Press.

6. Razeghi, M. (2009). Fundamentals of Solid State Engineering (3rd ed.). Springer.

7. Morkoç, H. (2008). Handbook of Nitride Semiconductors and Devices. Wiley-VCH.

8. Casey, H. C., and Panish, M. B. (1978). Heterostructure Lasers: Part A. Academic Press.

9. Shockley, W., and Read, W. T. (1952). Statistics of the Recombinations of Holes and Electrons. Physical Review, 87(5), 835.

10. Hall, R. N. (1952). Electron-Hole Recombination in Germanium. Physical Review, 87(2), 387.

11. Henry, C. H., and Lang, D. V. (1977). Nonradiative capture and recombination by multiphonon emission in GaAs and GaP. Physical Review B, 15(2), 989.

12. Blood, P., and Orton, J. W. (1992). The Electrical Characterization of Semiconductors: Majority Carriers and Electron States. Academic Press.

13. Reggiani, L. (Ed.). (1985). Hot-Electron Transport in Semiconductors. Springer.

14. Piprek, J. (2003). Optoelectronic Devices: Advanced Simulation and Analysis. Springer.

15. Jain, S. C., Willander, M., Narayan, J., & Overstraeten, R. V. (2000). III–V nitrides: Growth, characterization, and properties. Journal of Applied Physics, 87(3), 965–1006.