Direct Experimental Observation of Ultrafast Bimolecular and Auger Recombination Dynamics in Hexagonal Boron Nitride

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Hexagonal boron nitride (hBN) is a wide, indirect bandgap semiconductor with significant potential for ultraviolet and mid-infrared optoelectronic applications, the efficiency of which is critically dependent on the carriers' dynamics. Here, we report on the room-temperature dynamics of photoexcited free carriers in exfoliated ^{10}B-enriched hBN (99%). Using ultrafast ultraviolet-pump, near-infrared-probe transient transmission spectroscopy, we analyze the material's response on femtosecond to hundreds of picosecond timescales. We identify three distinct carrier recombination mechanisms and quantify their rates using the standard ABC model [1]. A slow, fluence-independent process, attributed to Shockley–Read–Hall (SRH) recombination via impurities and defects, is characterized by a rate constant of $A \sim 3.9 \times 10^{9}$ s^{-1}. At moderate free carrier densities 10^{16} cm^{-3}, bimolecular recombination becomes dominant, with a rate constant $B \sim 2.0 \times 10^{-7}$ cm^{-3} [2]. At high excitation densities >10^{17} cm^{3}, Auger recombination is observed, which is a key contributor to quantum efficiency "droop" in optoelectronic devices. The deduced Auger coefficient C is exceptionally large, ranging from 10^{-24} to 10^{-26} $cm^{6}s^{-1}$[3]. These results indicate that the Auger recombination rate in hBN is significantly larger than typically reported for other nitride-based semiconductors [4,5], which is sufficient to negatively impact the internal quantum efficiency of hBN-based devices at high current injection. We propose that this enhanced Auger rate is likely linked to charge localization induced by inherent defects and impurities and is further exacerbated by the built-in polarization field resulting from significant strain (up to ~5.9%) present in the material. These findings are crucial for understanding and mitigating efficiency losses in future hBN-based optoelectronic technologies.

References

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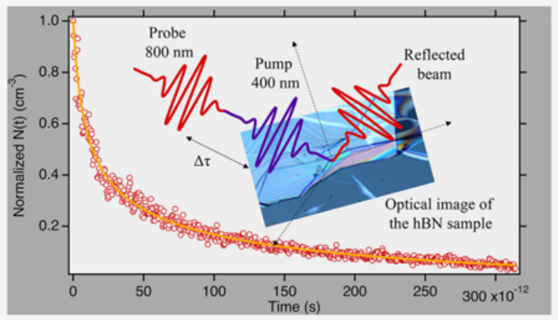

Figure 1: Normalized differential transients as a function of the time delay between the pump and probe pulses (inset: optical image of the sample illustrating the pump-probe principle).