Quantum-dot photodetectors: In search of optimal design for room-temperature operation

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Compared to quantum wells, quantum-dot structures provide more possibilities to control photoelectron kinetics and in this way to improve photodetector characteristics, such as photoconductive gain, responsivity, noise equivalent power, and operating temperature. Recently, infrared quantum-dot photodetectors (QDIPs) have shown the detectivity of 10^7– 10^8 cmHz$^{1/2}$/W and demonstrated their strong potential for various commercial applications. However, resources for further improvement of QDIPs based on traditional structures are very limited. In this presentation we will review novel ideas in QDIP design and identify the physical mechanisms that control the QDIP characteristics.

At room temperature, photoelectron capture in quantum-dot structures is determined by the electron diffusion in a complex relief of potential barriers around intentionally or unintentionally charged quantum dots. Photo-excitation of carriers from dots is determined by intradot kinetic processes, where electron-electron interaction strongly dominates over the electron-phonon scattering. Thus, both photoelectron excitation and capture turn out to be very sensitive to the electron population of the dots, which may be controlled by a proper choice of the structure geometry and modulation doping.

To optimize quantum-dot photodetectors for room temperature operation, we develop a detailed model of kinetic and transport processes in quantum dot structures. The model takes into account formation of potential barriers around dots, electron-phonon and electron-electron interactions in quantum dots and in the inter-dot space. Monte-Carlo techniques are used to investigate nonequilibrium effects in strong electric fields. Results of our simulations demonstrate that specific design and operating regimes provide wide possibilities for manageable (adaptive) kinetics of photoelectrons, which in turn allows significant improvements in detector performance.