Quantum Dots for Advanced Photonics

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ABSTRACT

Since the first proposal of semiconductor quantum dots in 1982, the quantum dots (QDs) have been intensively studied for both fundamental solid-state physics and advanced device applications. Full quantum-mechanical confinement of electrons has enabled the realization of high-performance quantum lasers, high-sensitivity quantum dot infrared detectors, and advanced non-classical light sources. Moreover, embedding a single quantum dot inside a photonic nanocavity has provided a new platform for studying solid-state cavity quantum electronics (cavity-QED).

In this lecture, we introduce some of fundamentals related to light-matter interaction in the QD structures. The first part is devoted to basic electronic and optical properties, including electronic states, the optical transition, the optical selection rule, and the optical gain. The discrete energy model of the QDs leads to the notion of so-called phonon bottleneck which brings the inhibition of energy relaxation of electrons into the QDs, due to the quasi-monochromatic LO phonon. However, experimental studies clearly show injected electrons can be relaxed into the QDs. We discuss this unconventional realization, taking account of the finite LO phonon life time due to vibration anhamonicity of phonons.

In the second part, the fundamentals of semiconductor quantum optics including cavity QED are described. In particular, we discuss both the strong and weak light-matter coupling regimes with the QD embedded in photonic nanocavities. The two regimes lead to the cavity polariton and enhanced Purcell effect in stimulated emission/spontaneous emission, respectively.

The final part discusses recent advances in quantum dot photonics, such as silicon photonics integrating QD lasers, QD nano-lasers, and single photon sources based on III-Nitride QDs operating above room temperature.

BIOGRAPHY

Yasuhiko Arakawa received the B.E., M.E., and Ph.D. degrees in electronics and electrical engineering from the University of Tokyo, Tokyo, Japan, in 1975, 1977, and 1980, respectively. In 1980, he joined The University of Tokyo as an Assistant Professor and became a Full Professor in 1993. He is currently Specially-Appointed Professor of the Institute for Nano Quantum Information Electronics, The University of Tokyo, and also Professor Emeritus of The University of Tokyo. His major research interests include physics, growth, and photonics application of the quantum dots. He received numerous awards including ISCS Young Scientists Award in 1990, ISCS Quantum Devices Award in 2002, Leo Esaki Award in 2004, IEEE/LEOS William Streifer Award in 2004, the Fujiwara Award in 2007, the Prime Minister Award in 2007, the Medal with Purple Ribbon in 2009, IEEE David Sarnoff Award in 2009, the C&C Award in 2010, ISCS Heinrich Welker Award in 2011, OSA Nick Holonyak Jr. Award in 2011, JSAP Isamu Akasaki Award in 2012, Japan Academy Prize in 2017, and IEEE Jun-ichi Nishizawa Medal in 2019. He was elected as a Foreign Member of the US National Academy of Engineering (NAE) in 2017. He is a Life Fellow of IEEE and Fellows of OSA, JSAP, and IEICE.