Physics of Nano-Optoelectronics Functions : Theoretical and experimental progress towards functional devices and systems

Hirokazu HORI
Interdisciplinary Graduate School of Medicine and Engineering,
University of Yamanashi
4-3-11 Taleda, Kofu 400-8511, Japan
Email: hirohori@yamanashi.ac.jp

Nano-optoelectronics devices and systems are those exerting novel functions based on the coupled configulations of electronic transport in the form of exciton confined within semiconductor nanostructures of arbitrary shape and optical near-field interactions between resonant excitonic states belonging to several isolated electronic confinment structures. Due to partly coherent and partly dissipative features of the coupled electronic and optical systems under an influence of local environmental systems and the hierarchical property of optical near-field interactions [1], the nano-optoelectronics devices and systems have potential to exhibit complexity far beyond the conventional system architectures for signal transfer and informtion processing. The author's group has demonstrated the functionality of several basic configurations of nano-optoelectronics devices based on modulated multi-layered quantm well structure of diluted magnetic semiconductor (ZnMnCdSe), corresponding to shaped quantum confinment structures of excitons, using the optical near-field imaging technique of local photon emission with extremely high spatial position reproducibility under external magnetic field up to 9 T based on a low temperature STM-assisted near-field optical microscopy. In such basic configurations employed, the applied magnetic field locally modulates the shape of each electronic confinment potential for excitons as well as the Zeeman-shifted resonance between excitonic states in isolated electronic sysmets. This realized magnetic-field control of the coupled electronic transport and optical near-field interaction dynamics and resulting photon emission via complicated coupled processes.

Study of optical near-field interactions between nanometer-sized isolated electronic systems reveals number of basic problems remain unsolved related to electrodynamics and quantum mechanics. One of the most important issues is the optical excitation transfer via optical near-field interactions. Due to the nature of strong light-matter coupling, the optical properties of matter and the nature of electromagnetic fields are strongly modified from the mean-field properties by the environmental structures and the excitation/dissipation processes.

Accordingly, the physical quantities conserved during the near-field interaction turn out to be dependent on the environmental conditions. In order to treat the problems of optical near-field excitation transfer, we should employ theory of electromagnetic interaction based on the half-space problems where evanescent electromagnetic waves play the dominant role [2]. Several problems related to elementary processes have been solved on the bases of angular-spectrum representation of scattered fields and second quantization of electromagnetic fields involving evanescent waves employing the triplet-mode descriptions related to the optical sources and detectors [3]. For further developments towards theoretical description of nano-to-macro coupling and evaluation of optical functions of sub-wavelength space, we should include the hierarchical properties of optical near-field interactions, the partly coherent and partly dissipative processes of near-field interactions reflecting the local environment, the natures of non-equilibrium open system related to the source-to-detector problem, and so on.

In this study, we consider the physical meaning of function in nanometer space and discuss on the fundamental processes of optical interactions of nanometer scale from these viewpoints.

[1] M. Naruse, T. Inoue, and H. Hori, Jpn. J. Appl. Phys., 46, 9A, 6095-6103 (2007)
[2] T.Inoue and H.Hori, Phys. Rev. A,63, 063805-1-16 (2001)
[3] T. Inoue and H. Hori , Progress in Nano-ElectroOptics, vol.4, pp.127-199 (2005).

Hirokazu Hori is a Professor of Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, Kofu, Japan. He was born in Shizuoka Prefecture, Japan, in 1955. He received the B.S., M.S, and Ph.D. degrees in Electronics, from Kyoto University, Kyoto, in 1978, 1980, and 1984, respectively. He was appointed a Lecturer of Electronics at Yamanashi University in 1983, and became an Associate Professor and Professor in 1986 and 2003, respectively. He spent the academic year 1988-1989 on leave at Department of Physics, University of Washington, Seattle, as a Visiting Associate Professor. He was the Chief Secretary of Nano-Optics Research Group (Optical Society of Japan) in 2006-2012. His research interests include quantum electronics, quantum optics, near-field nano-optics, spin-related surface science, statistical physics, plasma physics, and application of these to chemistry, biology, and medicine. He and Dr. M. Ohtsu published “Near-Field Nano-Optics”, Kluwer Academic/Plenum Publ., New York, 2000. He and Dr. T. Yoshioka published the Japanese translation of “What is life? The next 50 years, Speculation on the Future of Biology, ed. by M.P.Murphy and L.A.J. O’Neill, Cambridge Univ. Press, 1995”, Baifu-Kan, Tokyo, 2001.