Development of general EM response theories stimulated by a collaboration with Rodolfo Del Sole

K. Cho

Institute of Laser Engineering, Osaka University, Suita, Japan

The collaboration with Del Sole and D'Andrea in 1986 on polariton ABC problem made me aware of the fact that the first-principles linear microscopic susceptibility of matter is generally a separable integral kernel. This has served me as a great hint for developping (A) microscopic nonlocal response theory [1], which is quite suitable for the study of resonant processes in confined systems, and (B) a new form of macroscopic Maxwell equations (M-eqs) with a single susceptibility [2], derived from (A) by applying long wavelength approximation to its microscopic equations.

The scheme (A) turns out to be useful in studying the "size, shape, and internal structure"-dependence of the optical response of nanostructures in both linear and nonlinear regimes. It should be stressed that the theory correctly describe the size dependence both in- and outside long wavelength approximation, and that the radiative shift and width of matter excitations are taken into account with possible dependence on the size and shape of a sample. A peculiar effect expected from this theory was predicted as " nonlocality induced double resonance" effect, which was revealed in the resonant enhancement of four wave mixing in the slabs of GaAs in weakly confined regime.

The basic idea of the derivation of (B) from (A) is that all the EM response theories, from QED to macroscopic M-eqs, belong to a single hierarchy with higher and lower rank theories related via explicit approximations. Therefore, (B) is different from the conventional macroscopic M-eqs. Here also, the separability of microscopic susceptibility as an integral kernel plays an important role in applying the long wavelength approximation to the microscopic constitutive equation. The single susceptibility thus obtained for the macroscopic Maxwell equations is expressed in terms of the lower order moments of all the quantum mechanical transitions of matter, and it describes all the electric, magnetic and chiral susceptibilities. The symmetry properties of matter excitations are reflected through the matrix elements of current density contributing to the moments of the transitions.

As a most recent topic, a comparison with other type of single susceptibility theories is made [3]. Since the way to divide current density into the components of electric and magnetic polarizations is not unique [4], there can be several single susceptibility theories including that of Landau-Lifshitz [5]. Noting the defining equations of the different theories, we can establish a rewriting scheme among them with a conclusion that (B) is most recommendable because the choice of matter variable (current density) is most natural and because it is the only one giving the quantum mechanical expression of susceptibility in a general form.

References

[1] K. Cho, *Optical response of nanostructures: Microscopic Nonlocal Theory*, Springer Verlag, pp.1-167 (2003)
[2] K. Cho, *Reconstruction of macroscopic Maxwell equations: A Single Susceptibility Theory*, Springer Verlag, pp.1-131 (2010)
[3] K. Cho, Cond-Mat. arXiv: 1303.0355v1
[4] A. Chipouline, K. Simovski, and S. Tretyakov, Metamaterials **6** (2012) 77-120
[5] L. D. Landau and E. M. Lifshitz, *Electrodynamics of Continuous Media*, 1st ed. (Pergamon Press, Oxford, 1960), Sec.83, (Sec. 104 of 2nd ed., 1984)

**corresponding author: e-mail* k-cho@kcc.zaq.ne.jp