GENERAL THEORY OF IMAGE FORMATION FOR ALL OPTICAL MICROSCOPY AND OPTICAL COHERENCE TOMOGRAPHY

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We formulate an image formation theory for all optical microscopy with any light-matter interaction [1]. The type of interaction determines the upper limit of frequency cutoff in far-field microscopy as far as *a priori* information about a sample is not available (Fig. 1).

To incorporate optical coherence tomography (OCT) into our theory, we define a Fourier transform pair: a four-dimensional (4-D) amplitude spread function $h(x, y, z, t)$ in space-time domain and a 4-D pupil function $P(k_x, k_y, k_z, \omega)$ in wavevector/angular-frequency domain. The 4-D pupil function is defined for each excitation beam and signal light in an imaging system, and is restricted by a light spectrum and an NA. We also define a 4-D aperture $A(k_x, k_y, k_z, \omega)$ computed from all 4-D pupil functions in the imaging system as an instrumental function indicating optical resolution for the total system.

In some types of microscopy such as reflective confocal microscopy, optical transfer function (OTF) cannot be defined, but the 4-D aperture can still be defined and the OTF is calculated from the 4-D aperture if it exists. Thus the 4-D aperture is a more fundamental physical quantity than the OTF.

In this talk, we show a calculation rule of the 4-D aperture using our diagram technique and illustrate how images are formed through the 4-D aperture.

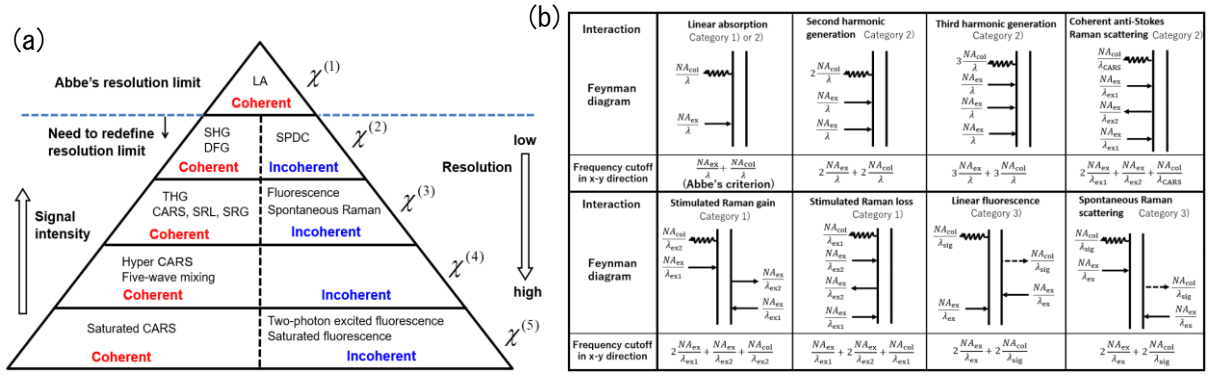

Fig. 1. (a) Classification of light-matter interactions. Only the $\chi^{(1)}$-derived interaction obeys Abbe's resolution limit $2NA/\lambda$. OCT is categorized as $\chi^{(1)}$. LA: linear absorption, SHG: second harmonic generation, DFG: difference frequency generation, THG: third harmonic generation, CARS: coherent anti-Stokes Raman scattering, SRG: stimulated Raman gain, SRL: stimulated Raman loss, SPDC: spontaneous parametric down-conversion. (b) A comparison of maximum frequency cutoff in x-y direction that each light-matter interaction intrinsically possesses. λ_{ex} and λ_{sig} are the excitation and signal wavelengths, respectively. NA_{ex} and NA_{col} are NAs of the excitation and signal-collection systems, respectively.

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