

Effects of Refractive Index Mismatch on Stimulated Raman Scattering and Coherent Anti-Stokes Raman Scattering Microscopy

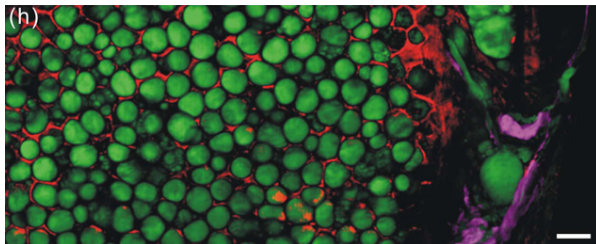
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Stimulated Raman Scattering Microscopy



White bar = 20 μm , combined SRS image of mouse ear skin with proteins (red) and lipids (green)
(Purple is blood from two photon absorption)

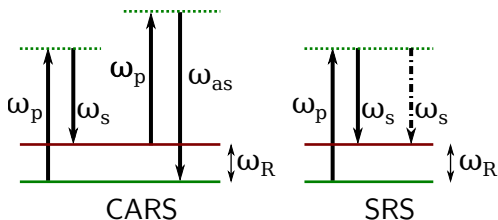
- No dyes
- Chemically specific

[1]Lu, F.-K. et al. Multicolor stimulated Raman scattering microscopy. *Molecular Physics* 110, 1927–1932 (2012).

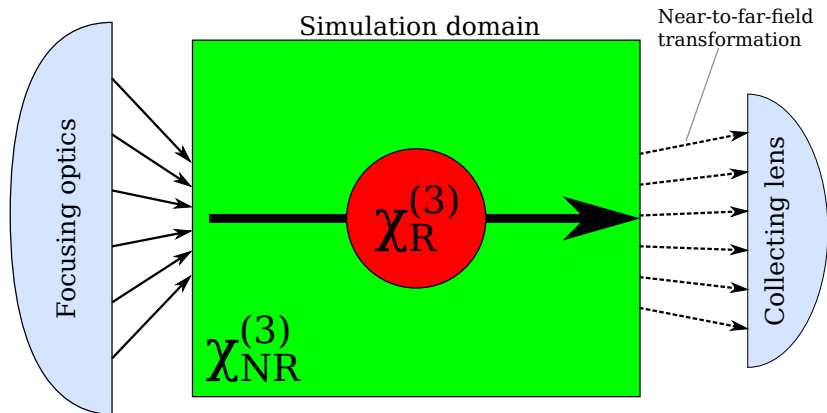
SRS and CARS

Processes of

- Coherent Anti-Stokes Raman Scattering (CARS)
- Stimulated Raman Scattering (SRS)



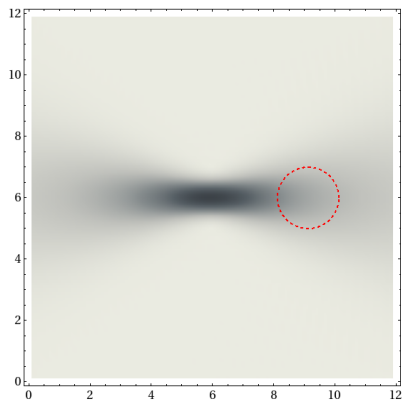
Computational electrodynamics



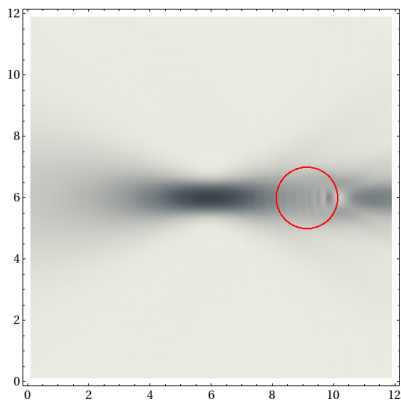
- Using Finite-Difference Time-Domain simulations

Single spherical object in a focused laser beam

Simulation of input pump beam field distribution



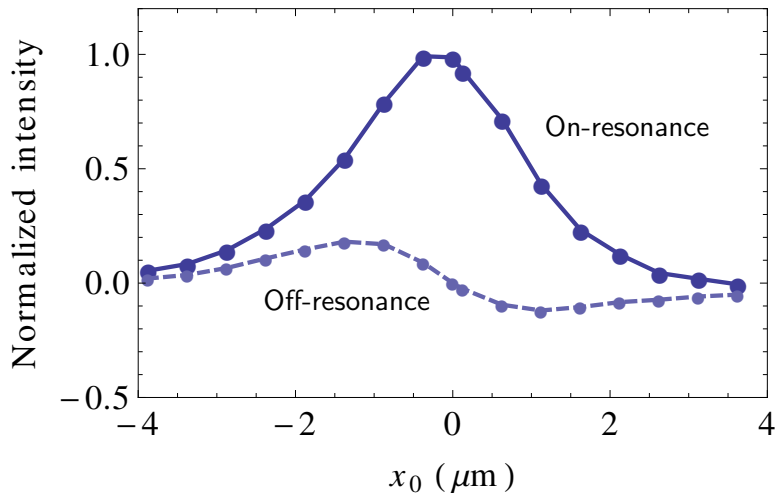
Refractive index matched



Refractive index mismatched

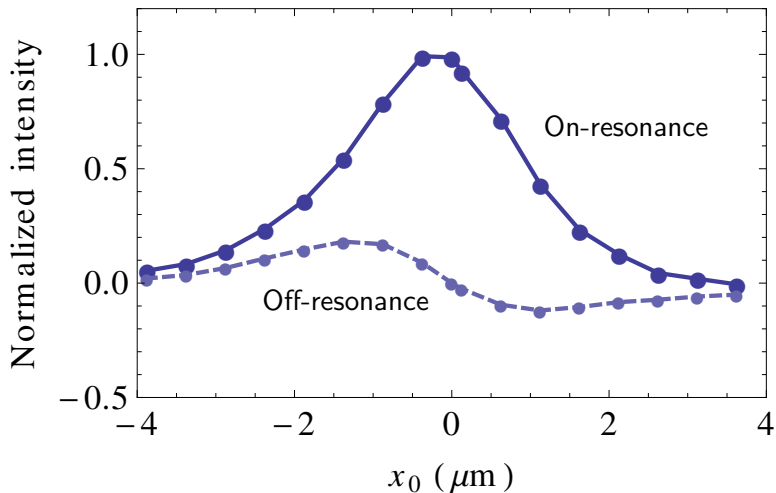
AM-SRS signal for oil droplet in water

Refractive index mismatched



AM-SRS signal for oil droplet in water

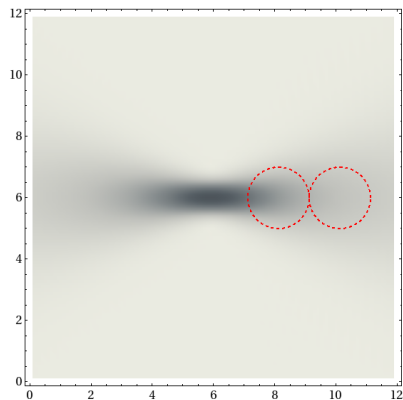
Refractive index mismatched



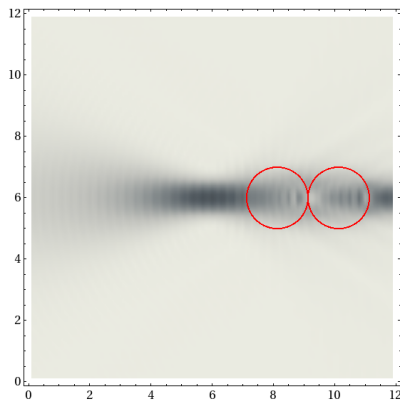
- Δn causes signal, not $\Delta\chi^{(3)}$

Two spherical objects in a focused laser beam

Simulation of input pump beam field distribution

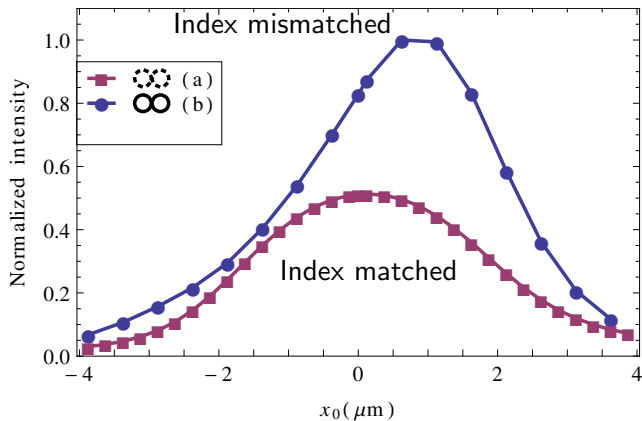


Refractive index matched



Refractive index mismatched

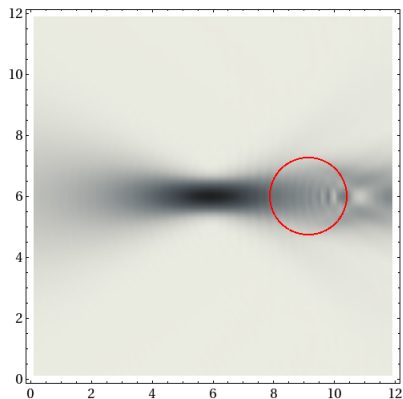
CARS for two resonant spherical objects



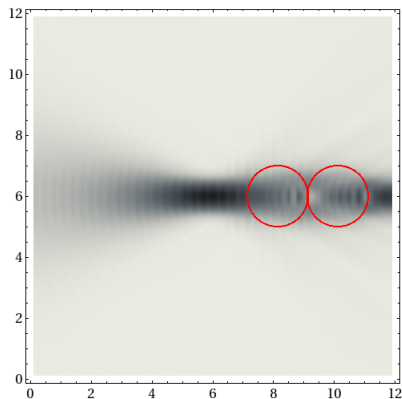
- Microlensing effect

Effect of object shape

Simulation of input pump beam field distribution



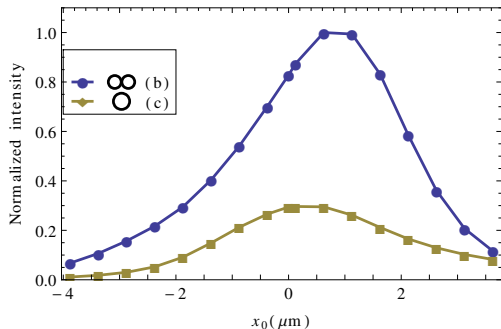
Refractive index mismatched



Refractive index mismatched

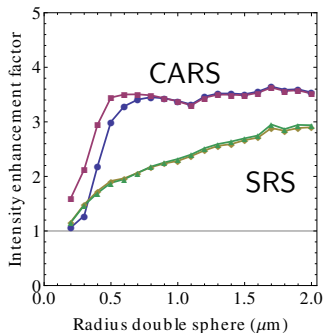
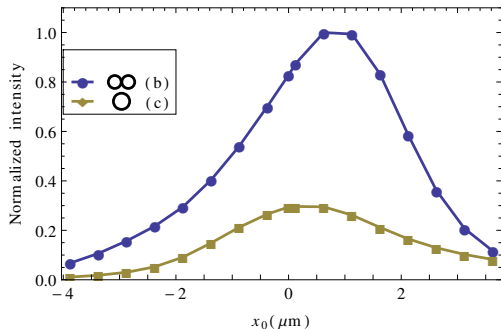
Effect of resonant object shape on SRS/CARS

Both cases index mismatched



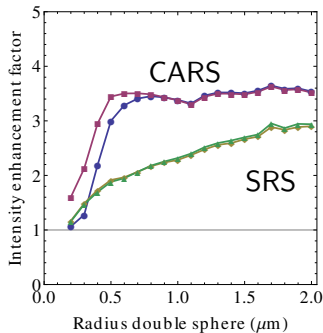
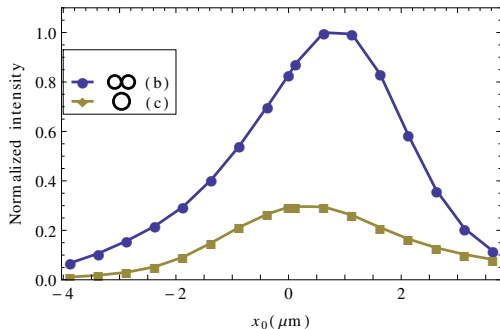
Effect of resonant object shape on SRS/CARS

Both cases index mismatched



Effect of resonant object shape on SRS/CARS

Both cases index mismatched



- Effect remains when separating spheres

Conclusion

Shape in the linear index of refraction can





- create off-resonant signals (can be avoided using FM or hyperspectral techniques),
- change perceived position of object in CARS/SRS image (cannot be avoided),
- measured molecular density in CARS/SRS image increased up to several times (cannot be avoided)

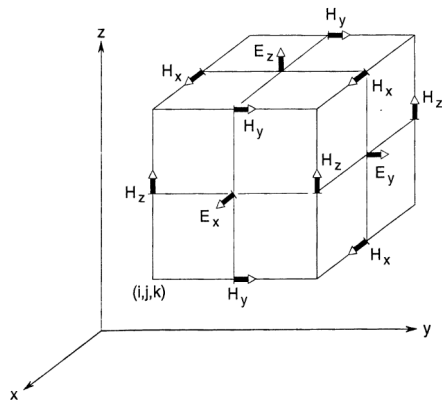
Thank you for your attention

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From direct discretization of

$$\frac{\partial \vec{D}}{\partial t} = \nabla \times \vec{H}$$

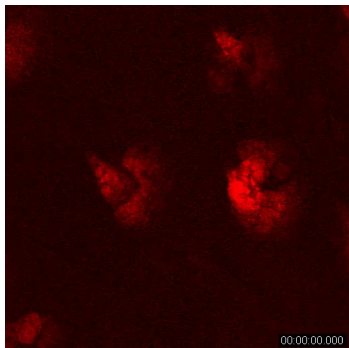
$$\frac{\partial \vec{B}}{\partial t} = -\nabla \times \vec{E}$$

$$\vec{D} = \epsilon \vec{E}$$

$$\vec{B} = \mu \vec{H}$$

SRS and CARS

- Molecule-specific without labels
- Video-rate
- 3D



[4]Saar, B. G. et al. Video-Rate Molecular Imaging in Vivo with Stimulated Raman Scattering. *Science* 330, 1368–1370 (2010).

Linear and Nonlinear Microscopes

Wave equation from Maxwell's equations:

$$\nabla \times \nabla \times E(\omega) - \frac{\omega^2}{c^2} E(\omega) = \mu\mu_0 P(\omega)$$

$$P(\omega) = \epsilon_0 \chi^{(1)}(\omega) E(\omega) + \\ \epsilon_0 \chi^{(3)}(\omega = 2\omega_1 - \omega_2) E^2(\omega_1) E^*(\omega_2) + \\ \dots$$

Linear

- Probes $\chi^{(1)}$
- 2D

Nonlinear

- Probes $\chi^{(N)}$, $N > 1$
- Small focal spot
- 3D through scanning