Dependence of the Non-Linear Electric Permittivity on System Size and Temperature

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Motivation:

Similarly to the macro-world, also in the nano-world the interaction between electromagnetic fields and metallic nanostructures can induce dissipation, namely heating processes. Therefore, the capability to predict the temperature reached by a system can be crucial when dealing with electronic, medical, biological or chemical applications [1,2].

Here, **we present a temperature dependent dispersive model for the dielectric function of a metallic medium**. Since temperature, in turn, depends on the intensity of the electromagnetic source and on the optical response of the medium itself, the model expresses non-linearity features.

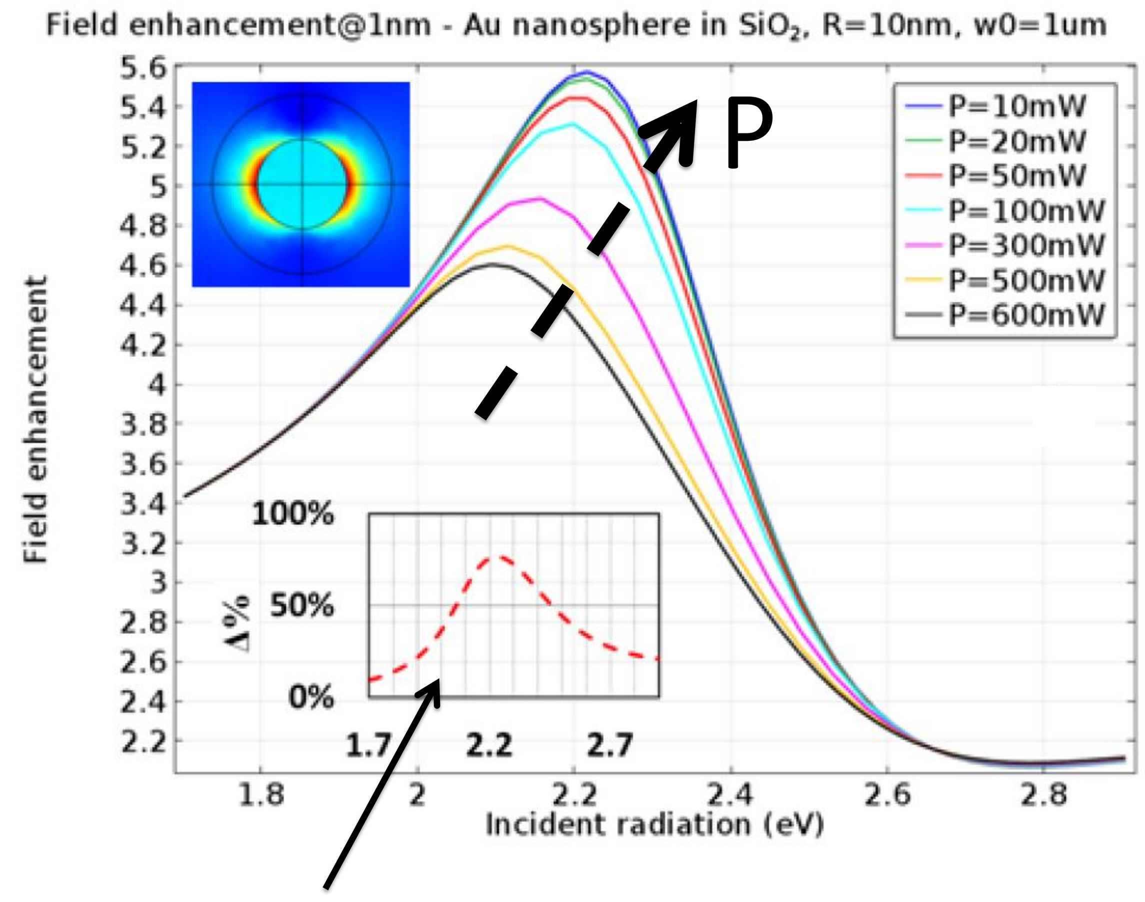
The model, which does not require any fitting parameter, can be utilized whenever the impact of temperature on the optical response of a system needs to be clarified and/ or when non-linearities might play a major role.

1. Power dependence

Gold nano-sphere (R=10nm) embedded in silica

- Far from resonance: overlap
- At resonance: different behaviours

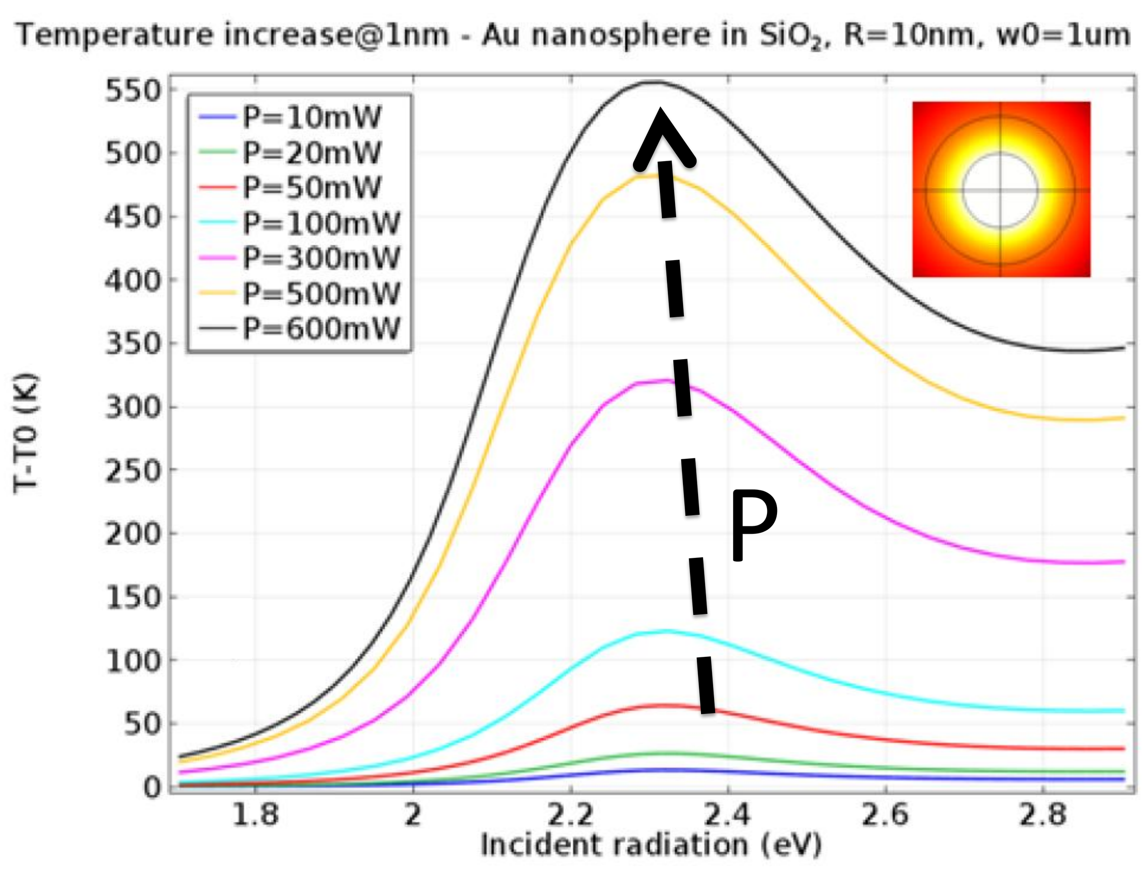
Temperature effects rise!



$\Delta\% = (\varepsilon_{im,600mW} - \varepsilon_{im,1mW})\%$

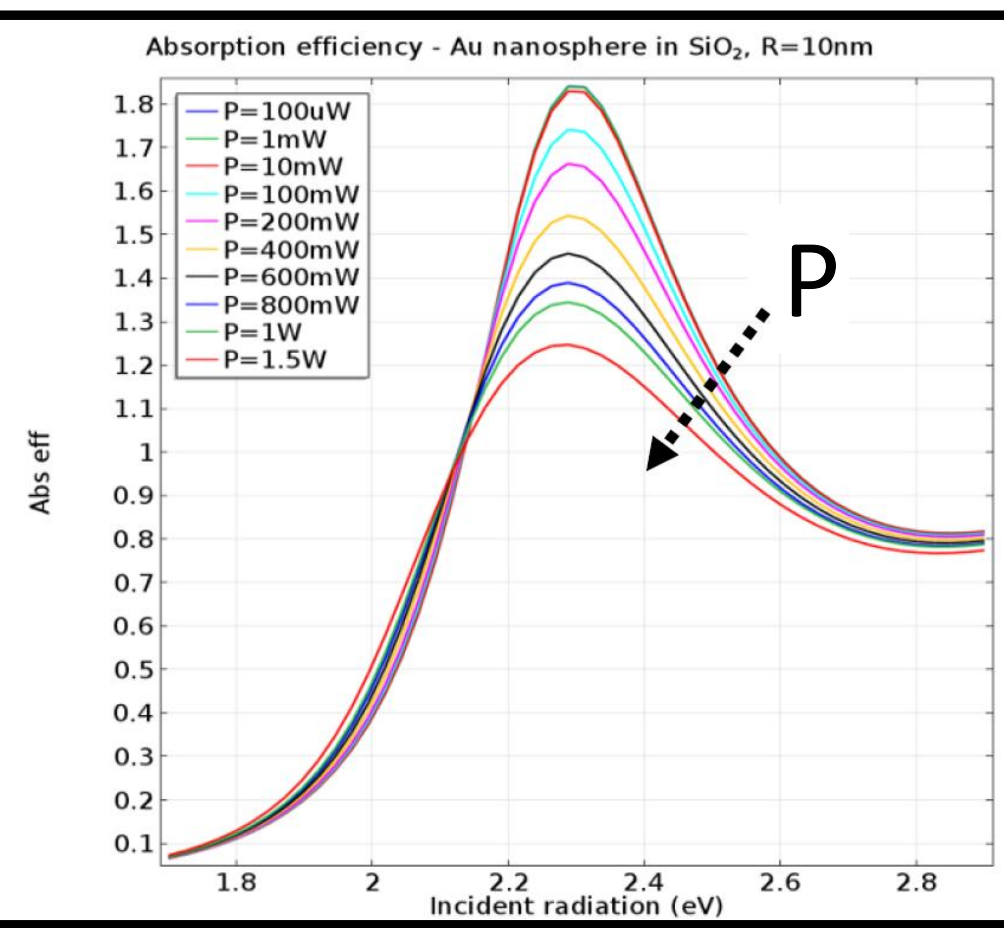
2. Temperature dependence

Temperature increase is proportional to the input power

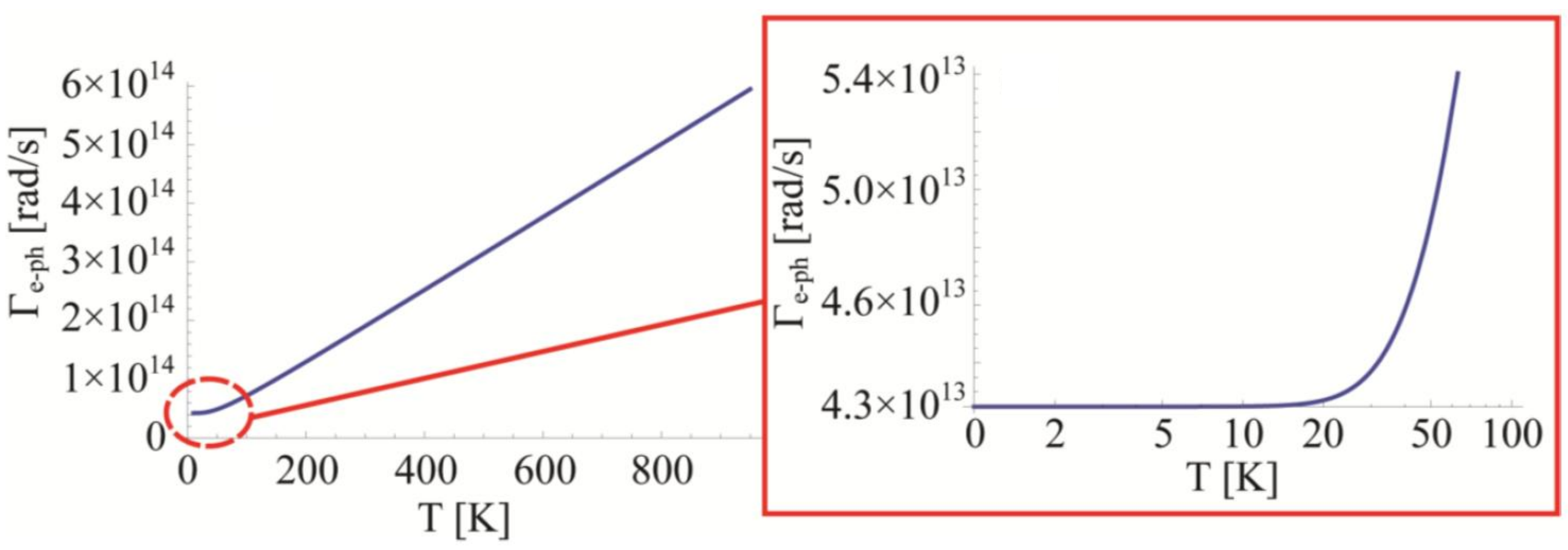


3. Absorption efficiency

Opposite behaviour with respect to 1. and 2.



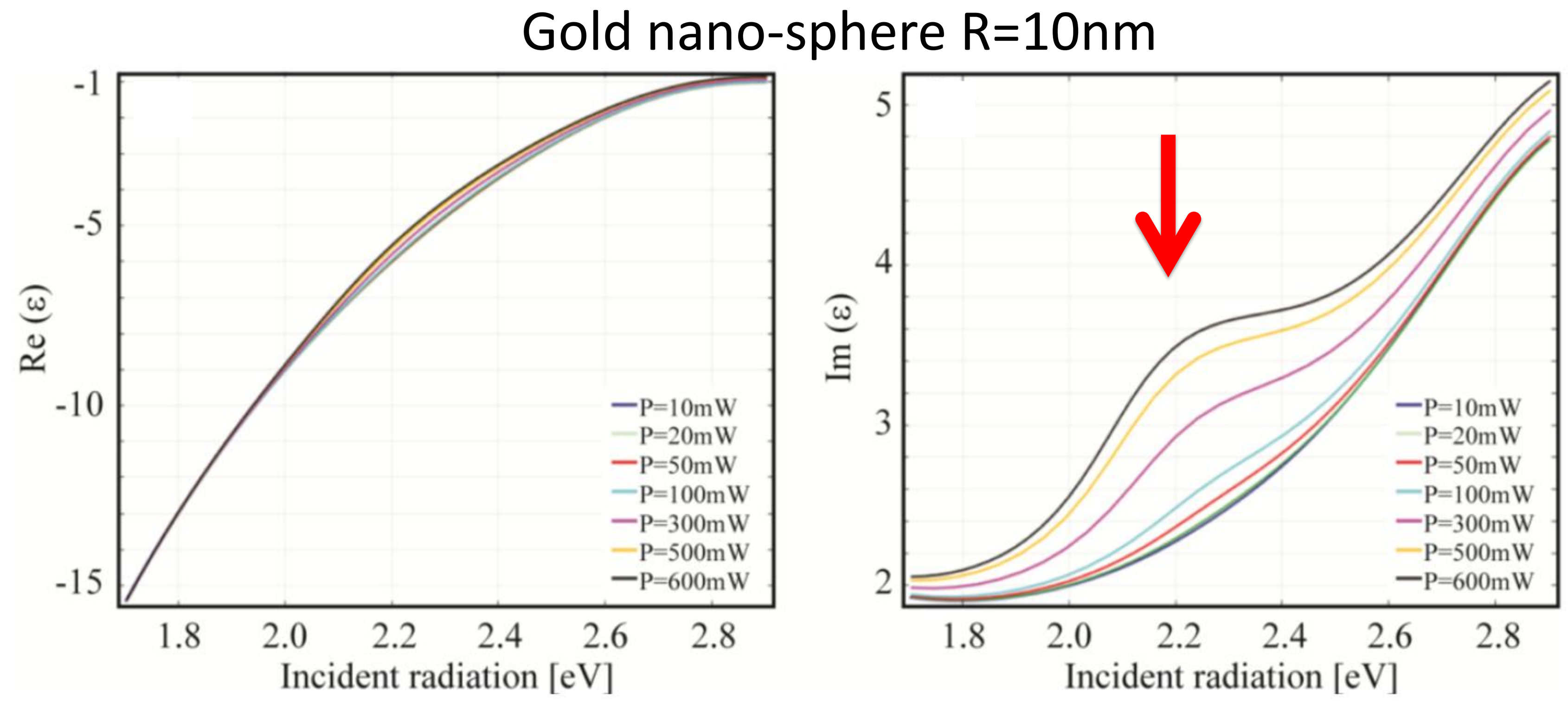
4. Electron-phonon scattering



Gold is considered

5. ε_{re} & ε_{im} : power dependence

Gold nano-sphere R=10nm



6. Some equations

The modelled dielectric function:

$$\begin{cases} \varepsilon_r = \varepsilon_{Intra-band} + \varepsilon_{Inter-band} = 1 - \dfrac{\Omega_p(T)^2}{\omega\left[\omega - i\eta\tilde{\Gamma}(T)\right]} + \displaystyle\sum_{j=1}^{m} \dfrac{f_j\omega_p^2}{\left(\omega_j^2 - \omega^2\right) + i\omega\Gamma_j} \\ \Omega_p(T) = \dfrac{\Omega_p}{\sqrt{1+3\gamma(T-T_0)}} \\ \tilde{\Gamma}(T) = \Gamma_0 + \Gamma(T) - \Gamma(T_0) \end{cases}$$

$$\downarrow$$

$$\Gamma(T) = \Gamma_{e-e}(T) + \Gamma_{e-ph}(T) + \Gamma_{e-surf} \quad \begin{cases} \Gamma_{e-e} = \dfrac{\pi^3}{12hE_F}\left[\left(k_B T\right)^2 + \left(\dfrac{h\omega}{2\pi}\right)^2\right] \\ \Gamma_{surf} = \dfrac{Av_f}{L_{eff}} \\ \Gamma_{e-ph} = \Gamma_0\left[\dfrac{2}{5} + \dfrac{4T^5}{\theta_D^5}\displaystyle\int_0^{\theta_D/T}\dfrac{z^4}{e^z-1}dz\right] \end{cases}$$

[3]

Conclusion: we have introduced a model for the optical and thermal description of plasmonic systems. The result was obtained through the deep analysis of the macroscopic media parameters, such as complex conductivity and dielectric function. In particular, the damping factor was modified in order to take into account the electron-electron, the electron-surface and the electron-phonon scattering rates. The latter, was in fact found responsible for any temperature dependence of the analyzed plasmonic systems.

[1] ***Engineering metallic nanostructures for plasmonics and nanophotonics***, N. C. Lindquist, P. Nagpal, K. M. McPeak, D. J. Norris, and S. H. Oh, Rep. Prog. Phys. 75, 036501 (2012).

[2] ***Plasmon Resonant Enhancement of Carbon Monoxide Catalysis***, W. H. Hung, M. Aykol, D. Valley, W. Hou and S. B. Cronin, Nano Lett. 10, 1314 (2010).

[3] ***Molding of Plasmonic Resonances in Metallic Nanostructures: Dependence of the Non-Linear Electric Permittivity on System Size and Temperature***, A. Alabastri, et al., Materials 6, 4879 (2013).