Non-linear optics of metals at the interband absorption edge

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Introduction

$c^{(3)}$ - NLO properties of noble metals have been studied in:

-Nanoparticles
-Percolation films
-Thin films

Results:

$\chi^{(3)}$ >> $\chi^{(3)}$ of silica

Sub-ps response time

Metals = losses!

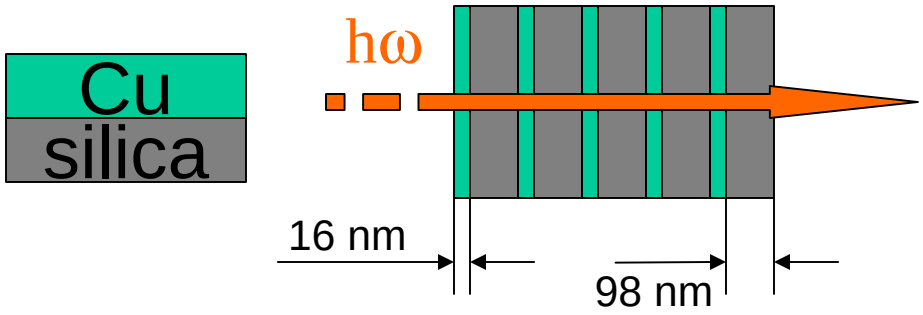
Interaction length L ~ skin depth

$\chi^{(3)}$ - mostly imaginary

Nonlinear response localized at the IB absorption edge

Artificial composite materials

1-D metal-dielectric PBG structure



Features:

Reduced loss (linear properties studied by Bloemer and Scalora [1])

Enhanced nonlinear response (theory by Bennink et al. [2])

Shifted peak of nonlinear response

Imaginary $\chi^{(3)}$ → nonlinear phase shift

Increased damage threshold

[1] M. Bloemer and M. Scalora, Appl. Phys. Lett. 72, 1676 (1998)

[2] R. S. Bennink, Y. Yoon, R. W. Boyd, J. E. Sipe, Opt. Lett. 24, 1416, (1999)

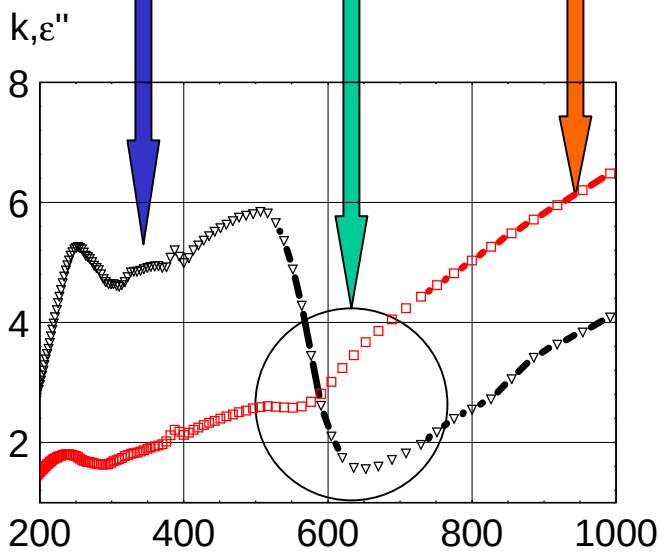
Loss mechanisms in metals

Absorption band

Reflection (Drude) region

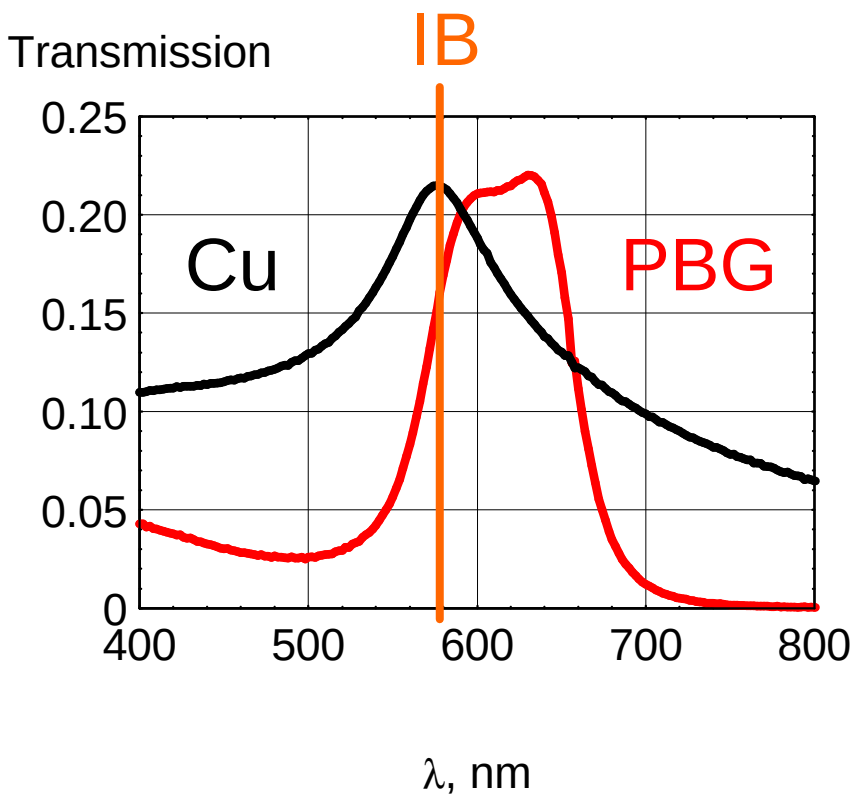
"Low" loss

Cu



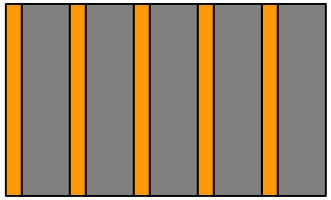
Handbook of Optical Constants of Solid, edited by E. D. Palik (Academic, New York, 1991)

Linear transmittance



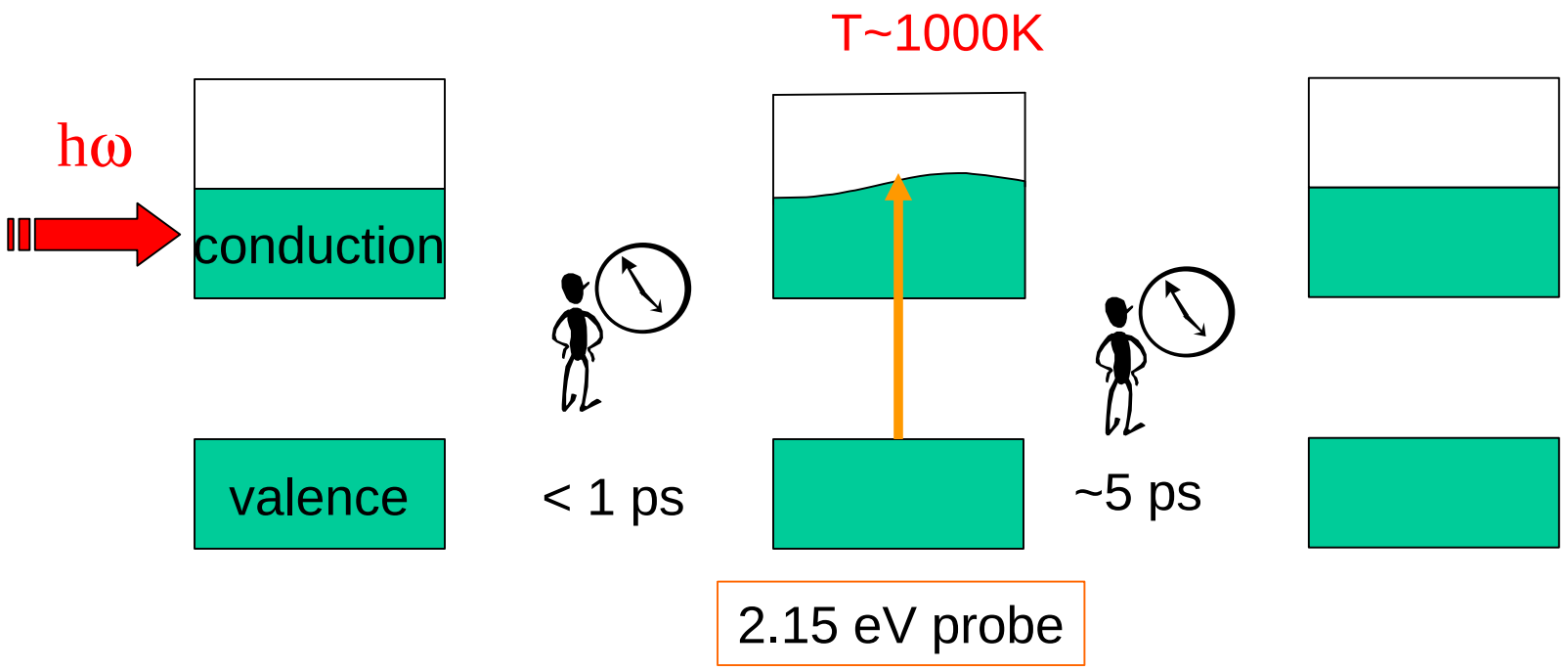
Copper

Cu: 40 nm film
PBG: 5x16/98 nm



Copper (80nm!) / silica

“Fermi smearing”

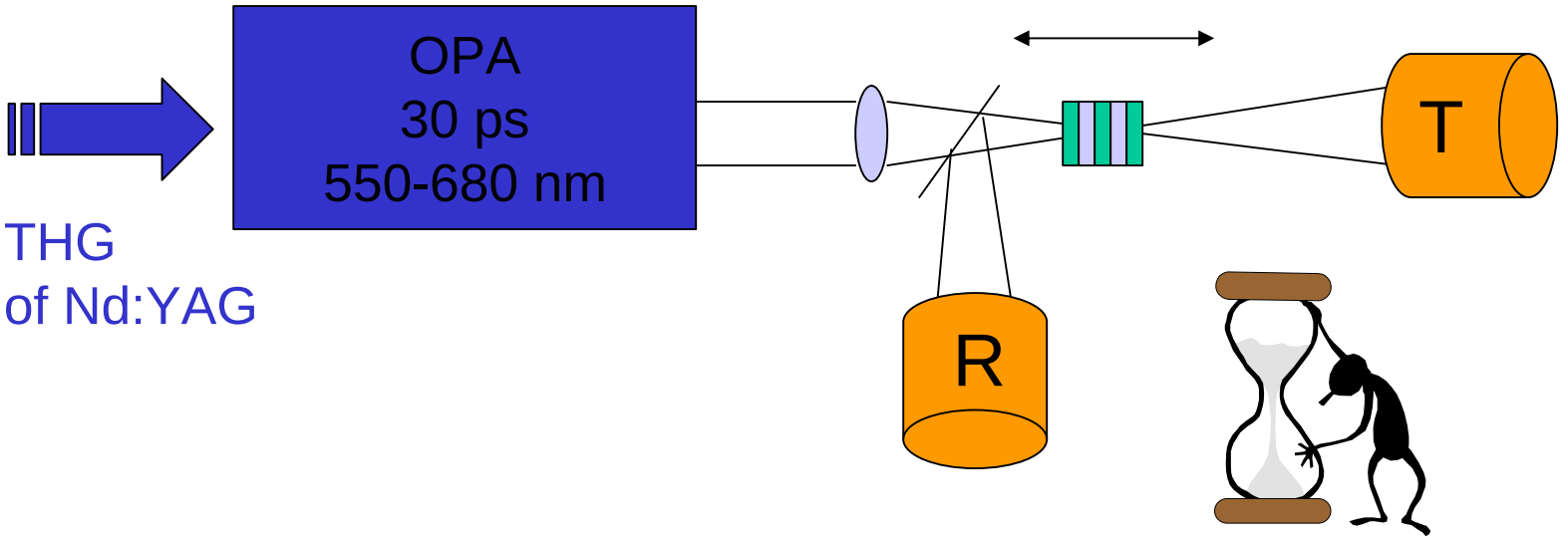


$$\Delta T \rightarrow \Delta e\,(E_{IB}) \rightarrow \text{change in optical properties}$$

Near interband edge, “Fermi smearing” is dominant nonlinear process

G. L. Eesley, Phys. Rev. B33, 2144 (1986)
H. E. Elsayed-Ali et al. Phys. Rev. Lett. 58, 1212 (1987)

Reflection/Transmission Z-scan

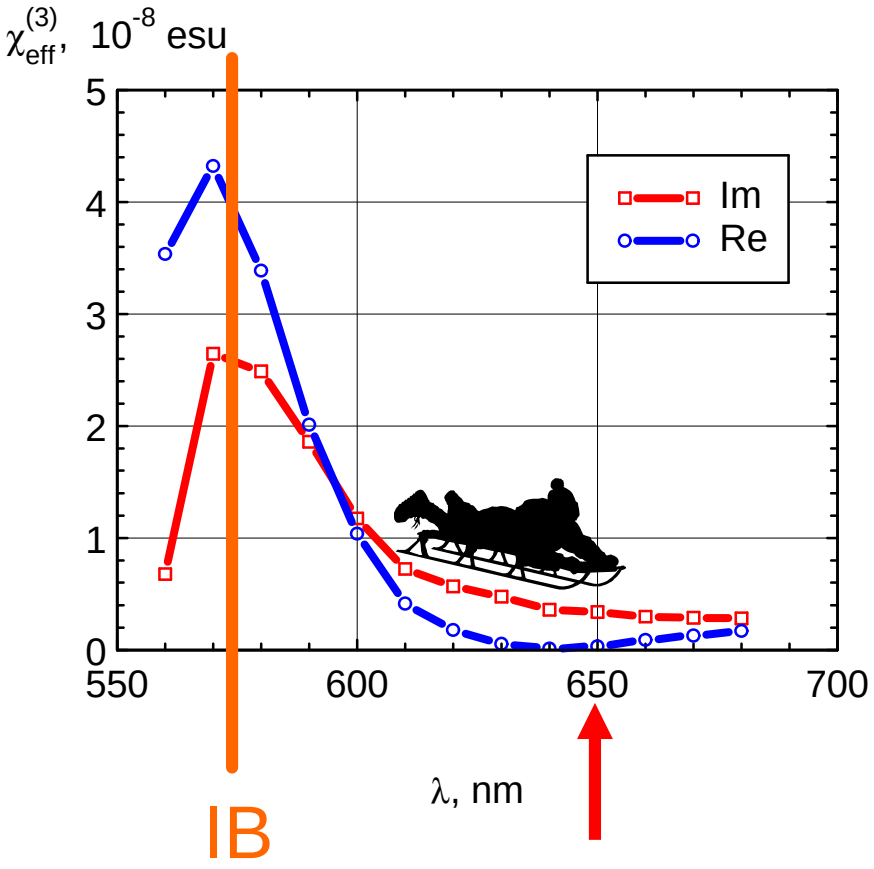


Pulse energy ~ 1mJ

$I = 100\ MW/cm^2$

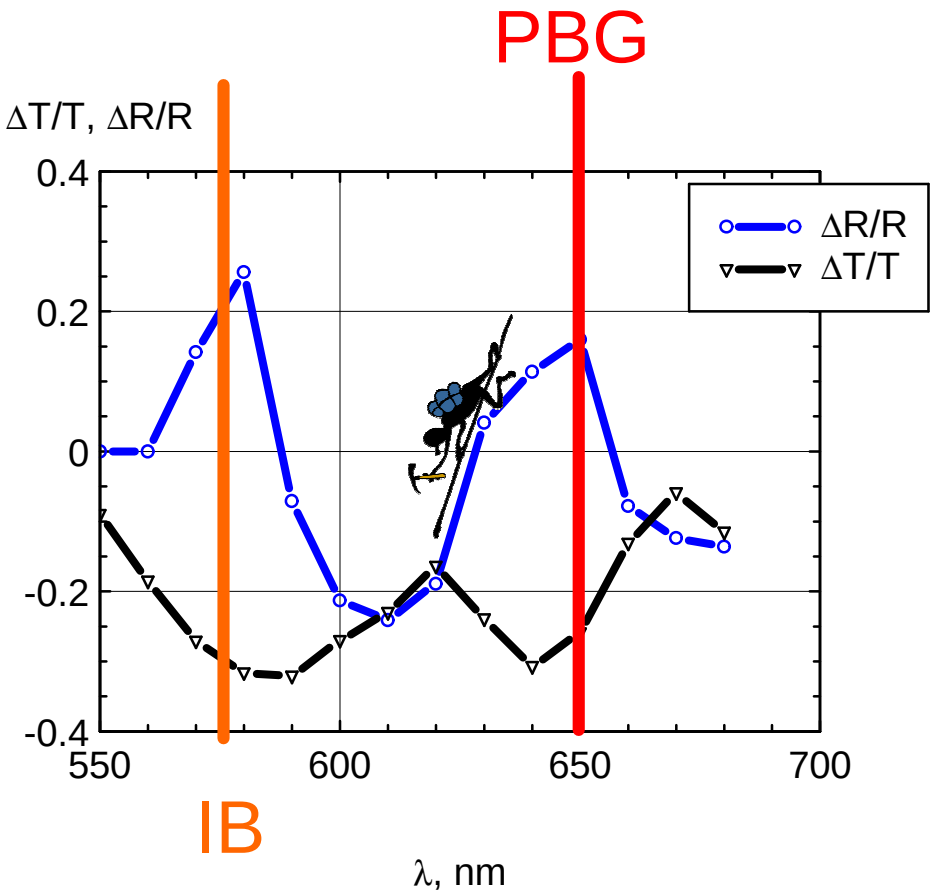
$$\frac{?R}{R}, \frac{\Delta T}{T} \rightarrow \Delta e' + \Delta e'' \rightarrow c_{eff}^{(3)}$$

Cubic susceptibility of pure Cu



Width of resonance ~ kT

Nonlinear response of PBG



$$\frac{\mathrm{Im}(c^{(3)}_{PBG})}{\mathrm{Im}(c^{(3)}_{Cu})} \cong 12$$

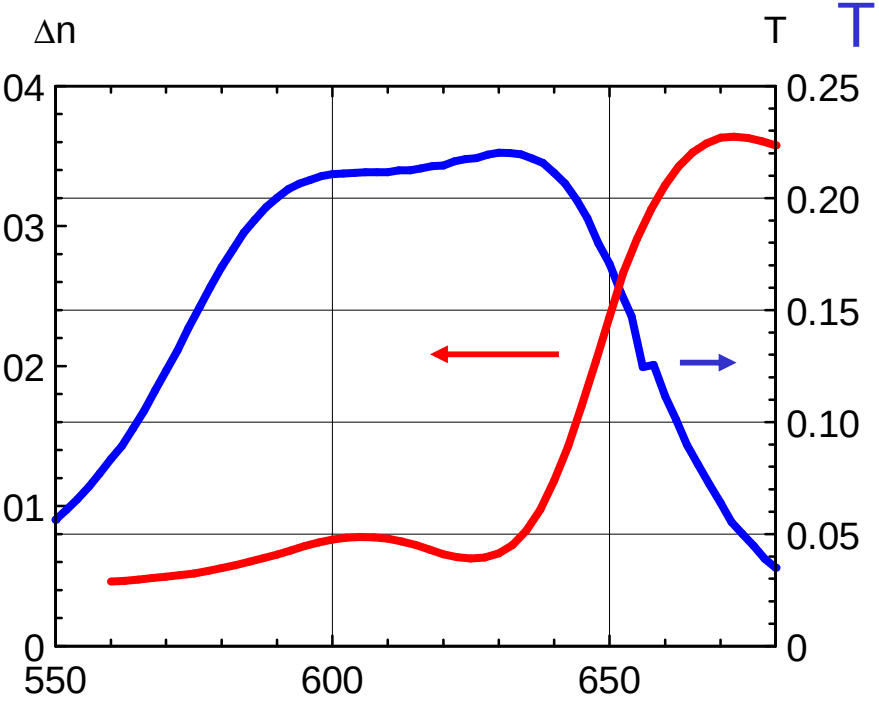
$$\frac{\mathrm{Re}(c^{(3)}_{PBG})}{\mathrm{Re}(c^{(3)}_{Cu})} \cong 20$$

Strong nonlinear features @ 650 nm!

Nonlinear phase shift in PBG

$$\Delta e = 0.1i \rightarrow ?\ \mathrm{f}$$

Phase shift



Conclusions

- Stable, artificial, solid-state NLO material
- Enhanced transmission (10X)
- Enhanced nonlinear response (20X) over extended spectral range (550-650 nm)