# Enhanced Nonlinear Optical Response of 1-D Metal-Dielectric Photonic Band-Gap Structures

**Nick N. Lepeshkin, Aaron Schweinsberg,**
**Ryan S. Bennink, Robert W. Boyd**

*The Institute of Optics,*
*University of Rochester, Rochester, NY 14627, USA*

and

**Robert L. Nelson**

*Air Force Research Laboratory, (AFRL/MLPO)*
*Wright-Patterson Air Force Base, Ohio 45433-7707 and*

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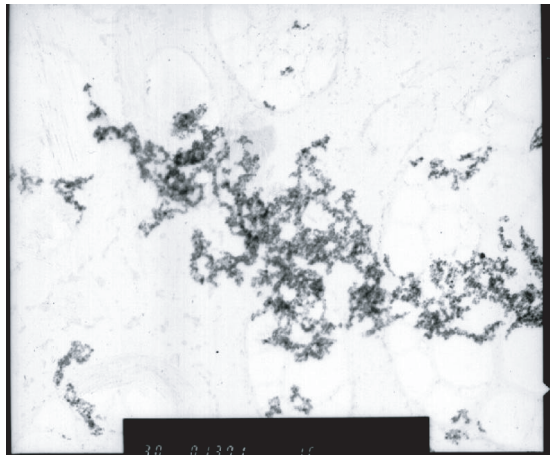
# How to Access Optical Nonlinearity of Metals?

$$\chi^{(3)}_{metal} \cong 10^{-8} - 10^{-7} \text{ esu} \quad \text{- opaque!}$$

$$\chi^{(3)}_{SiO_2} \cong 10^{-14} \text{ esu} \quad \text{- transparent!}$$

Discontinuous composite materials:

- colloidal solutions
- metal doped glasses
- granular metal films



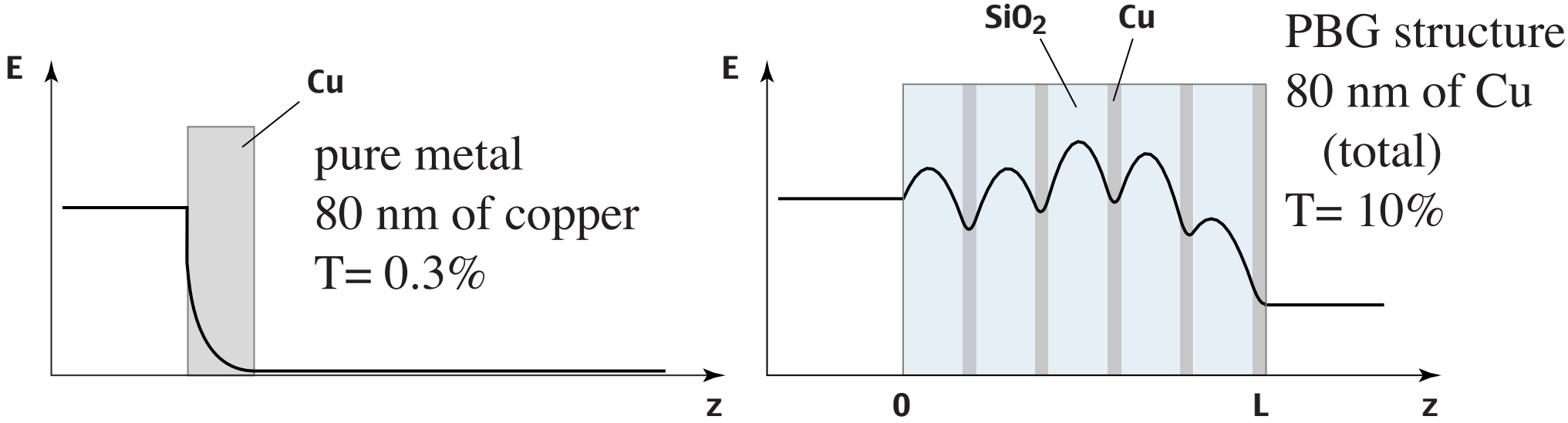
Layered periodic MD structures:

High transparency within specified spectral range (PBG effect)
Enhanced NLO response

# Accessing the Optical Nonlinearity of Metals with Metal-Dielectric PBG Structures

- Metals have very large optical nonlinearities but low transmission.
- Low transmission is because metals are highly reflecting (not because they are absorbing!).
- Solution: construct metal-dielectric PBG structure.

(linear properties studied earlier by Bloemer and Scalora)

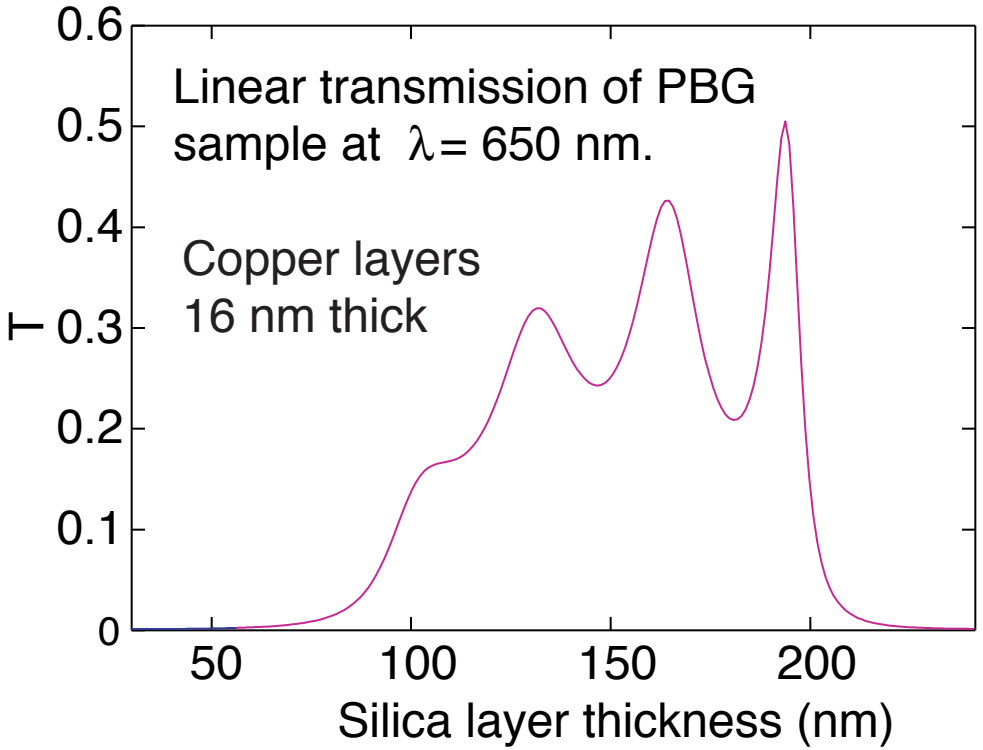


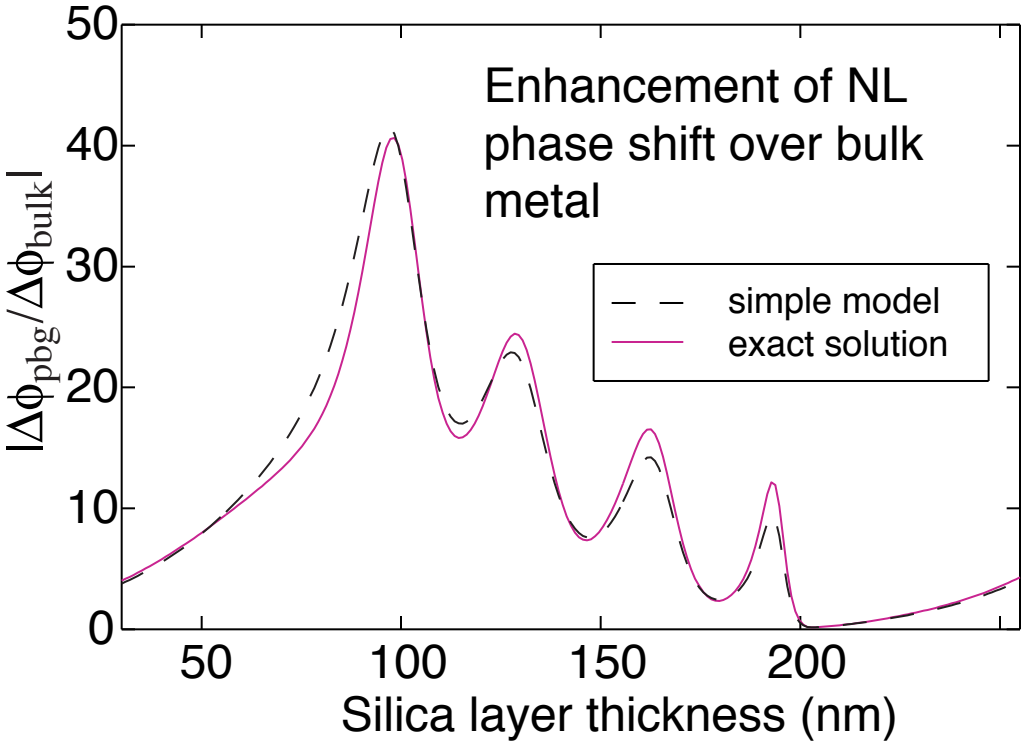

R.S. Bennink, Y.K. Yoon, R.W. Boyd, and J. E. Sipe Opt. Lett. 24, 1416, 1999.

# Accessing the Optical Nonlinearity of Metals with Metal-Dielectric PBG Structures

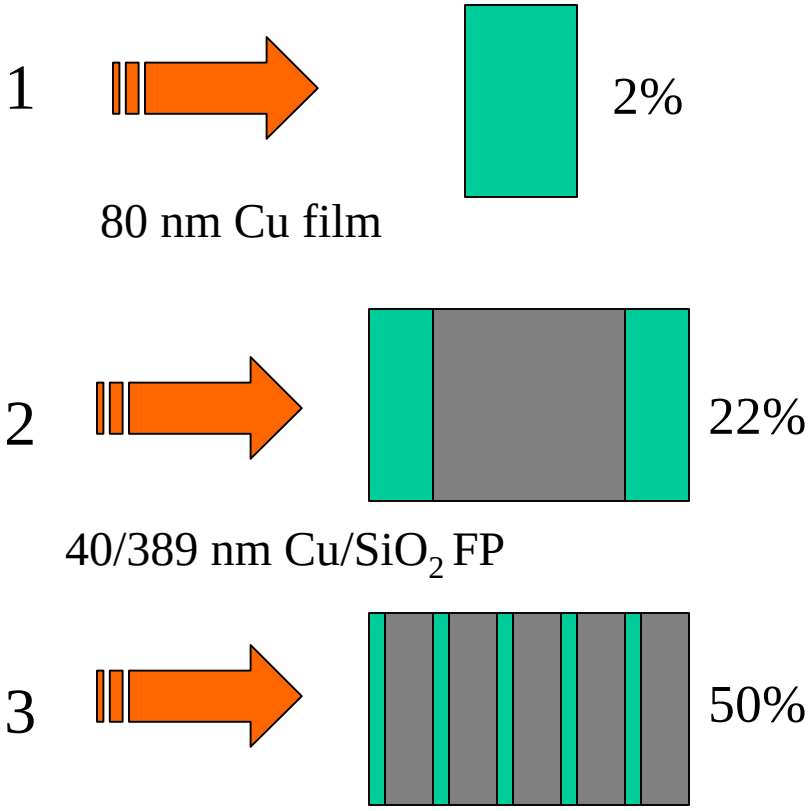
- Metal-dielectric structures can have high transmission.

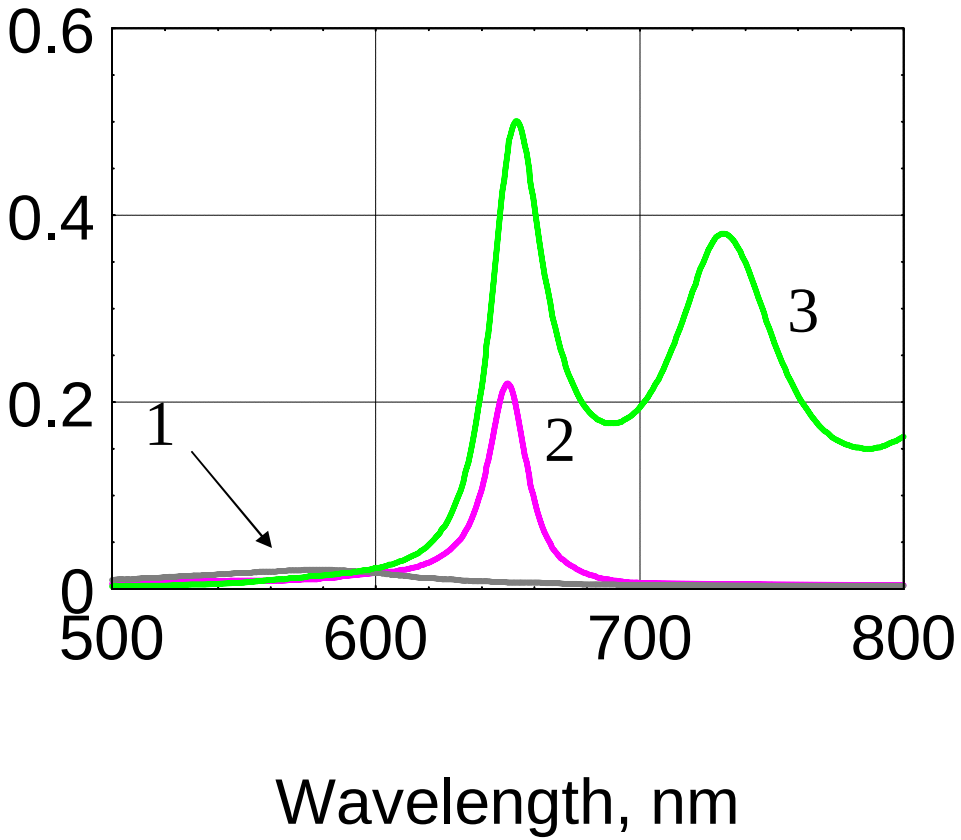
- And produce enhanced nonlinear phase shifts!



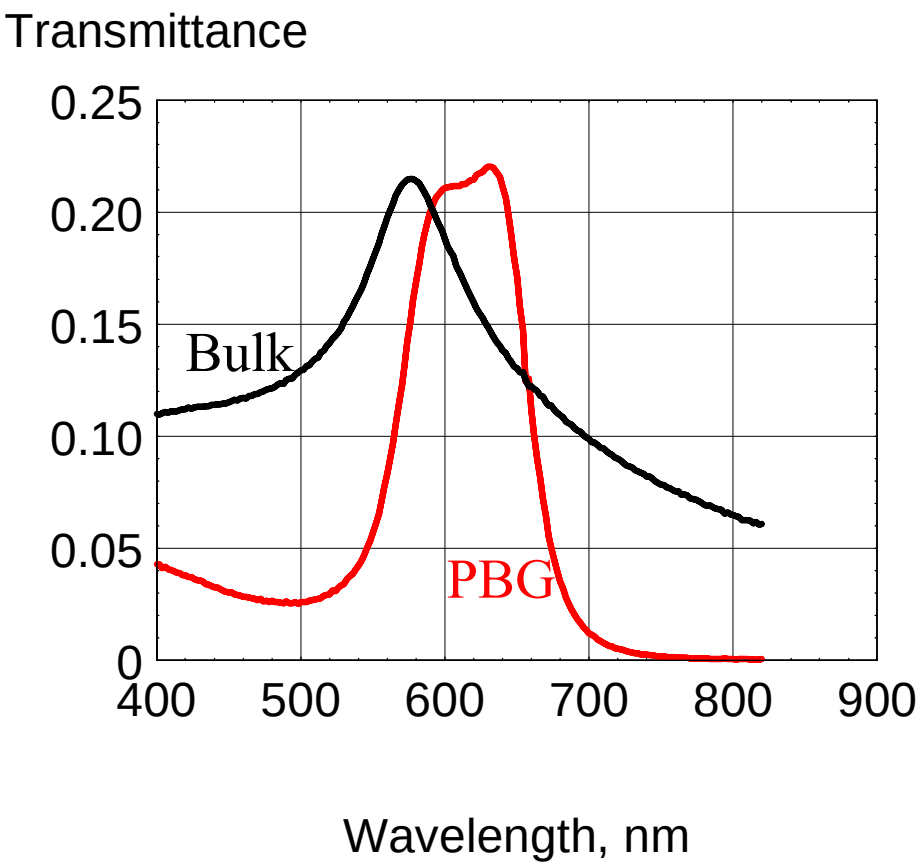
# 1-D Metal/Dielectric PBG structures

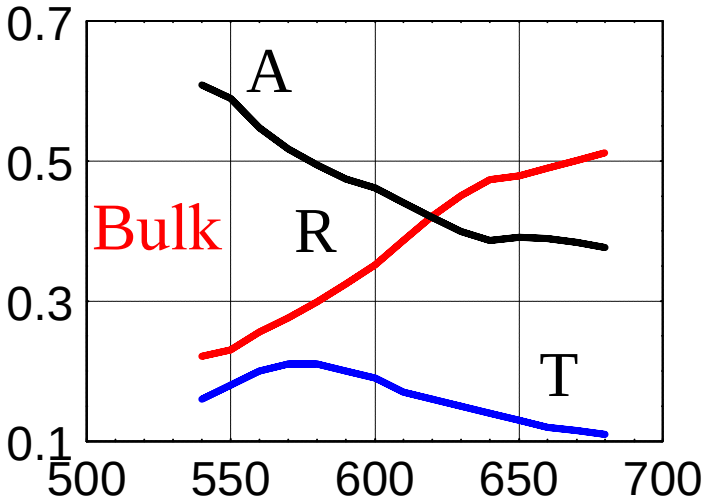


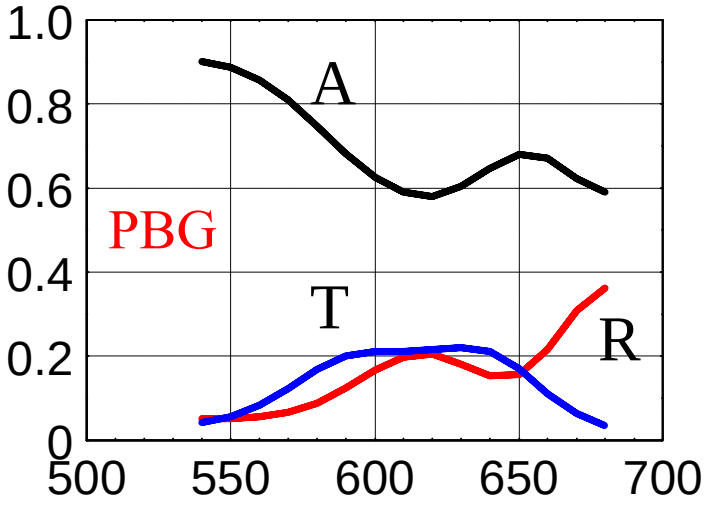



# Linear Optical Properties

Bulk: 40 nm Cu film
PBG: 5 x 16/98 nm Cu/SiO



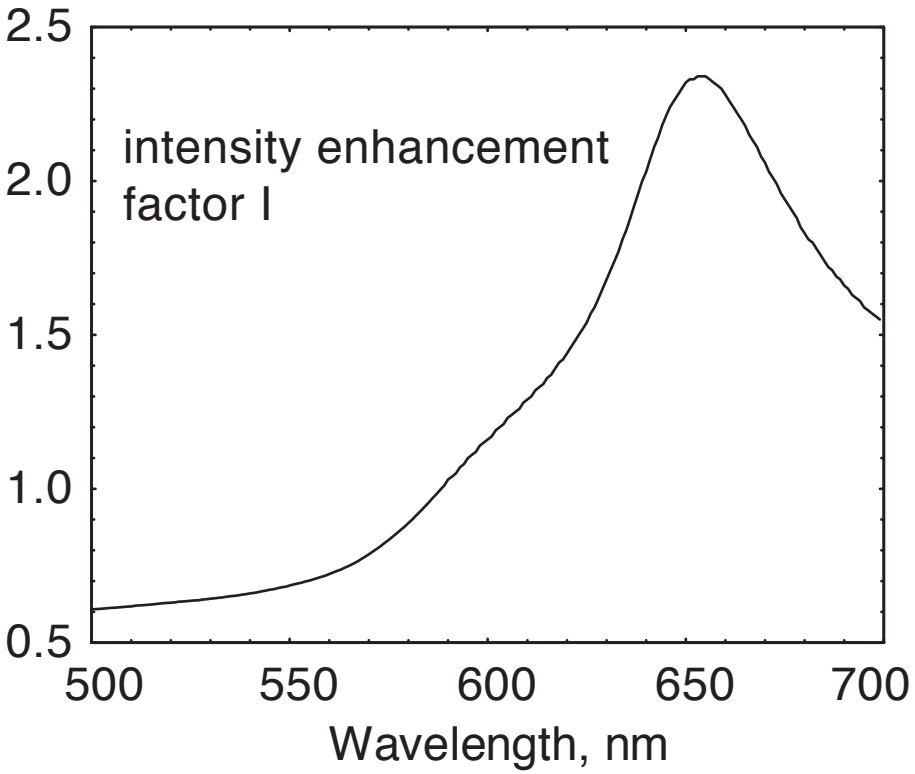



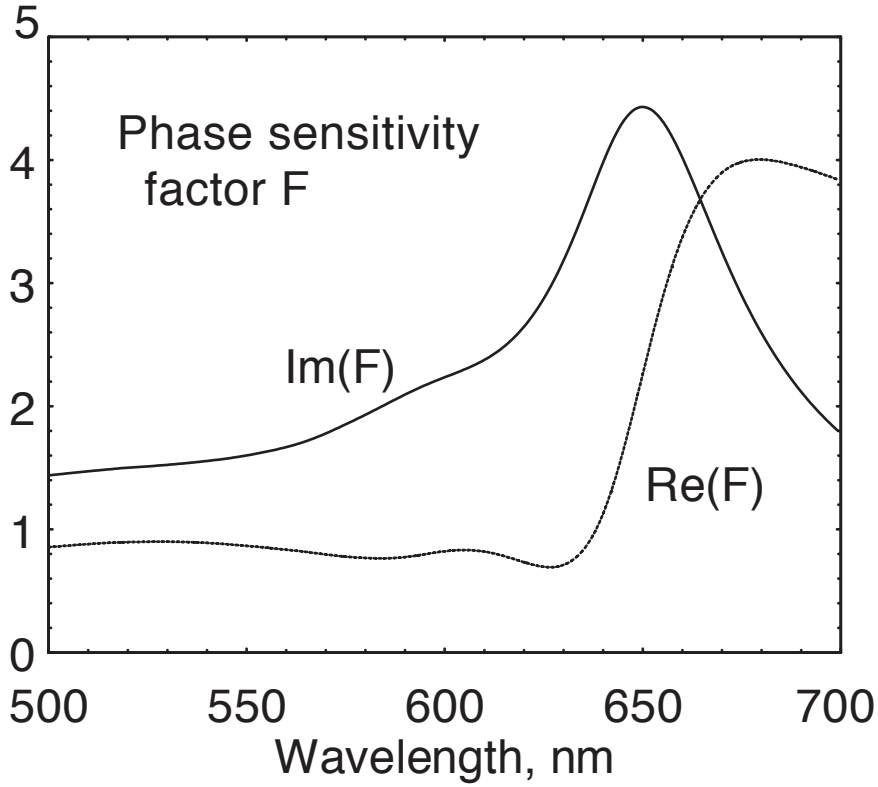
# Model of Enhanced Nonlinear Optical Response

$$\varepsilon \approx \varepsilon_{lin} + \chi_m^{(3)}\, I\, F\, E^2$$ where $$I = \frac{\left\langle E^2_{\mathrm{m,pbg}} \right\rangle}{\left\langle E^2_{\mathrm{m,bulk}} \right\rangle} \qquad F = \frac{\Delta\phi}{\frac{2\pi}{\lambda}\int \Delta n\, dz}$$

I = intensity enhancement factor

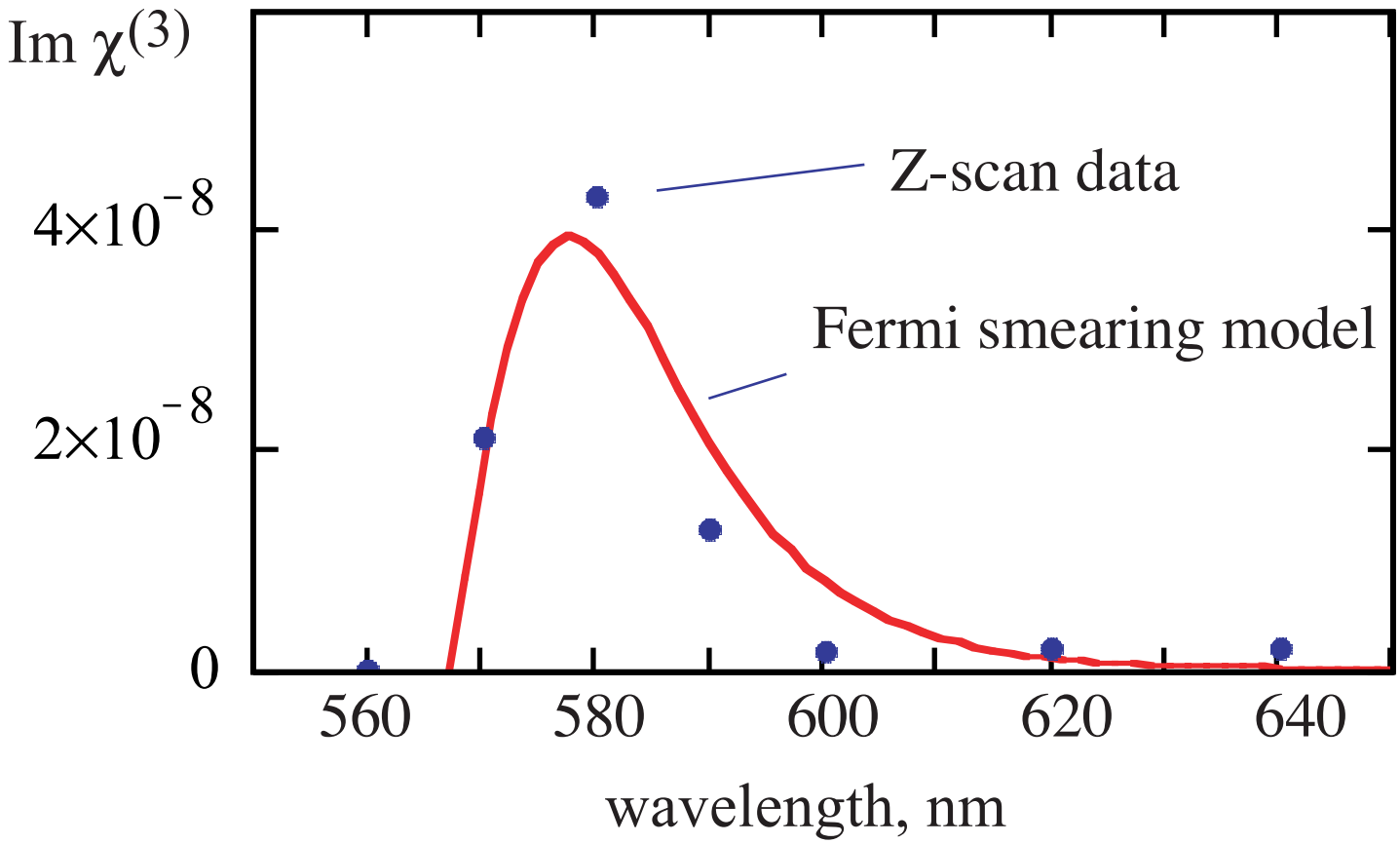
F = phase enhancement factor




I and F calculated numerically for our five layer design

# Nonlinear Susceptibility of Bulk Copper




- We find Im $\chi^{(3)}$ >> Re $\chi^{(3)}$ at all wavelengths where response is measurable
- Near interband threshold, Fermi smearing is dominant nonlinear process
  (Hache et al., Appl. Phys. A 47, 347-357 (1988))
- Width of resonance is approximately 4 *kT*

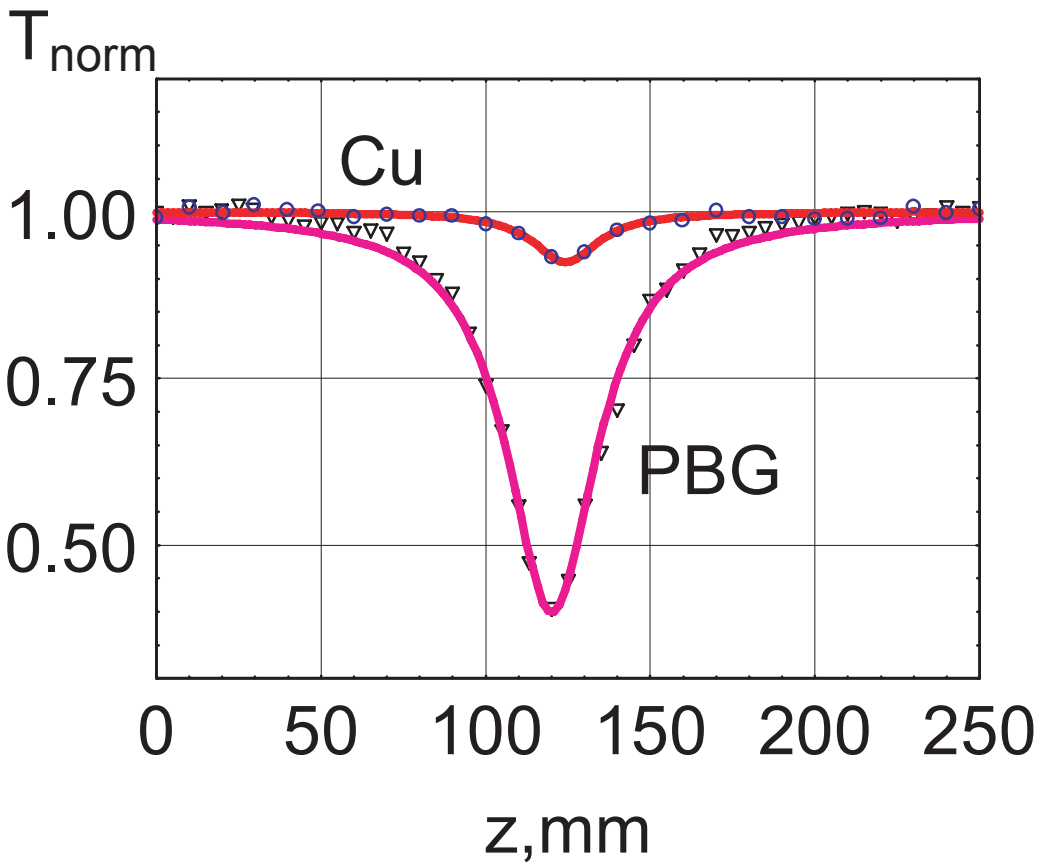
# Z-Scan Comparison of M/D PBG and Bulk Sample

Open-aperture Z-scan

(measures Im $\chi^{(3)}$)

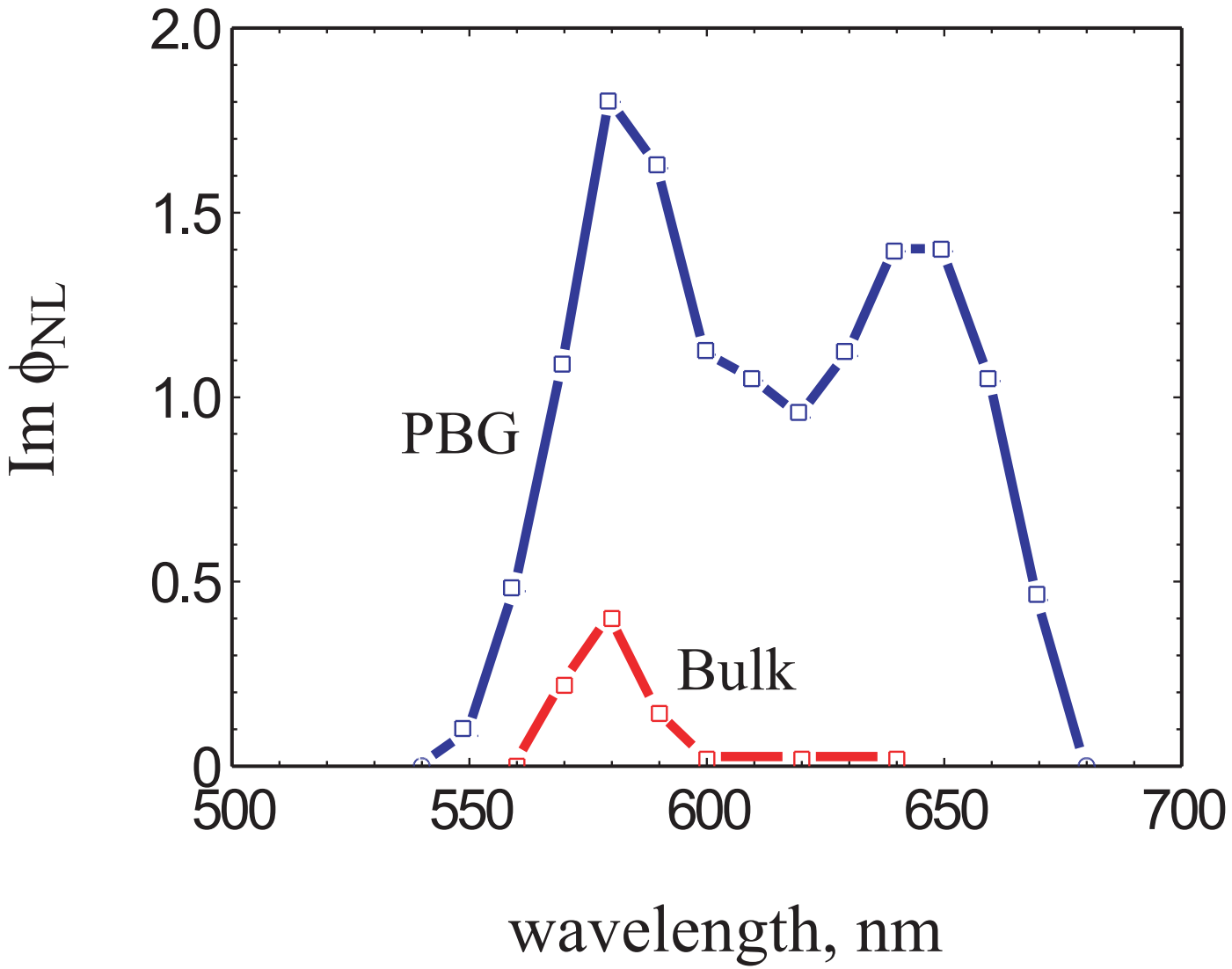
I = 500 MW/cm$^2$

$\lambda$ = 640 nm




$$\frac{\delta\phi''_{PBG}}{\delta\phi''_{Cu}} \cong 35$$

# Spectral Dependence of the Nonlinear Response




OPG:

t = 25 ps

Q = 2 to 5 mJ

I ≅ 100 MW/cm$^2$

# Conclusions

We produced a stable, artificial, solid-state NLO material with a tunable transmission band and high damage threshold.

We experimentally demonstrated enhanced nonlinear response of 1-D MD PBG structure. The enhancement factor was measured to be as high as 35.