



**Stanford Organic Electronics Lab**

# **Stopping Heat Flow: Aperiodic Superlattices for Thermoelectric Energy Conversion**

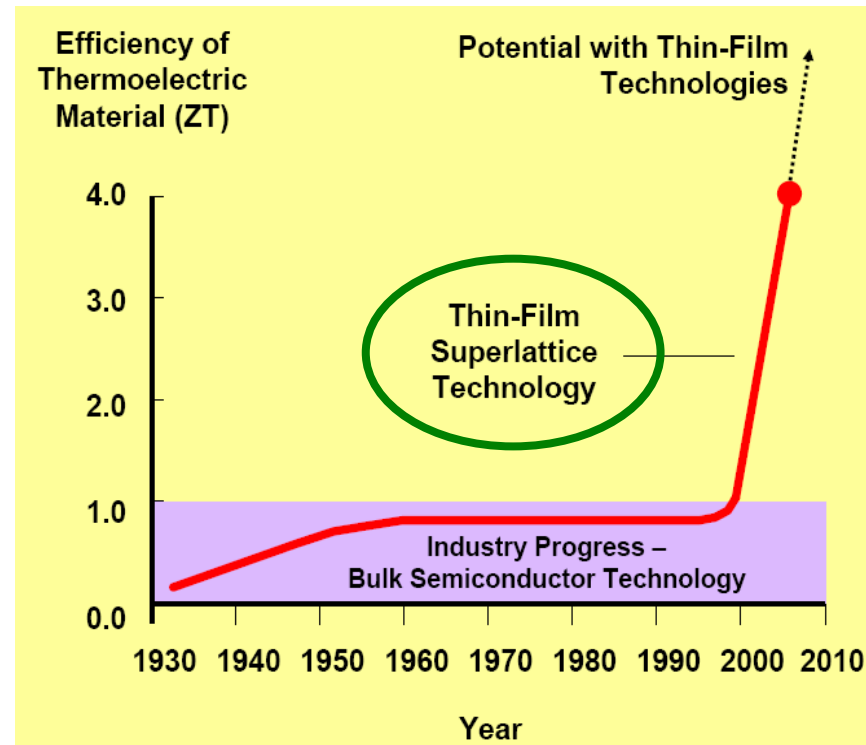
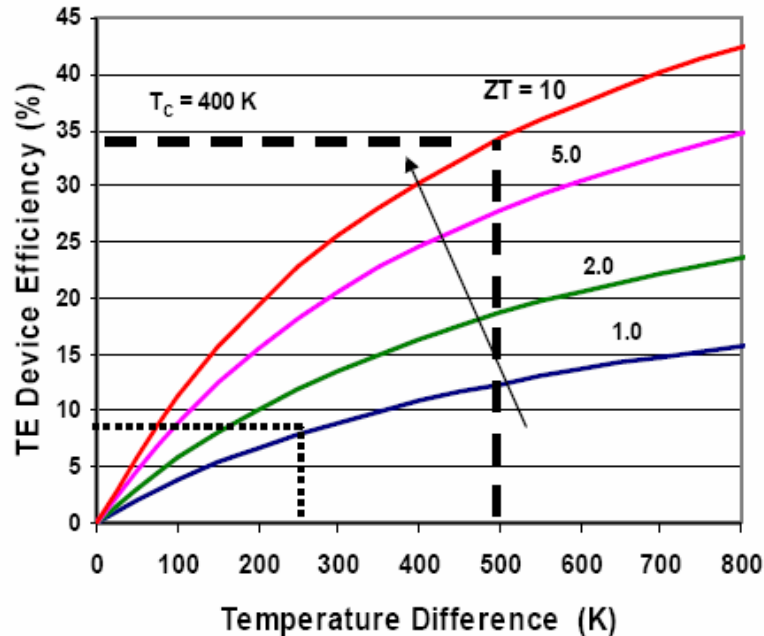
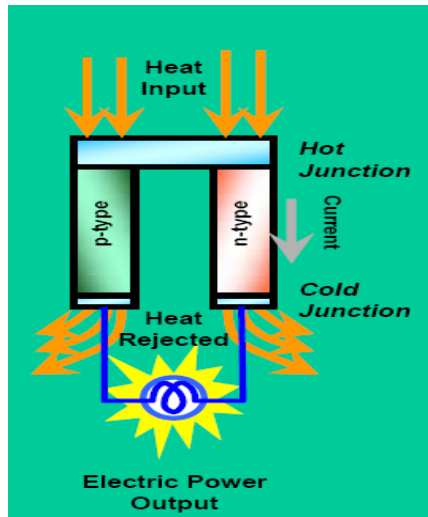
**Mukul Agrawal and Peter Peumans**

Electrical Engineering

Stanford University, Stanford, CA 94305

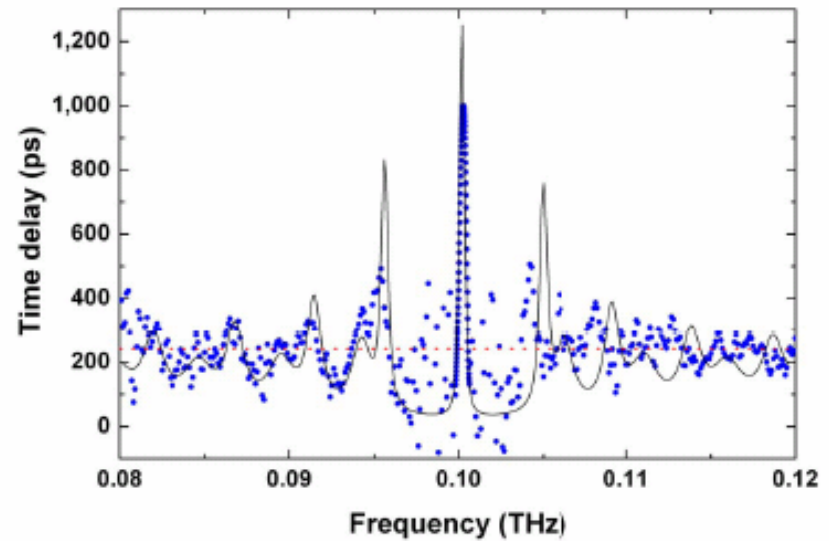
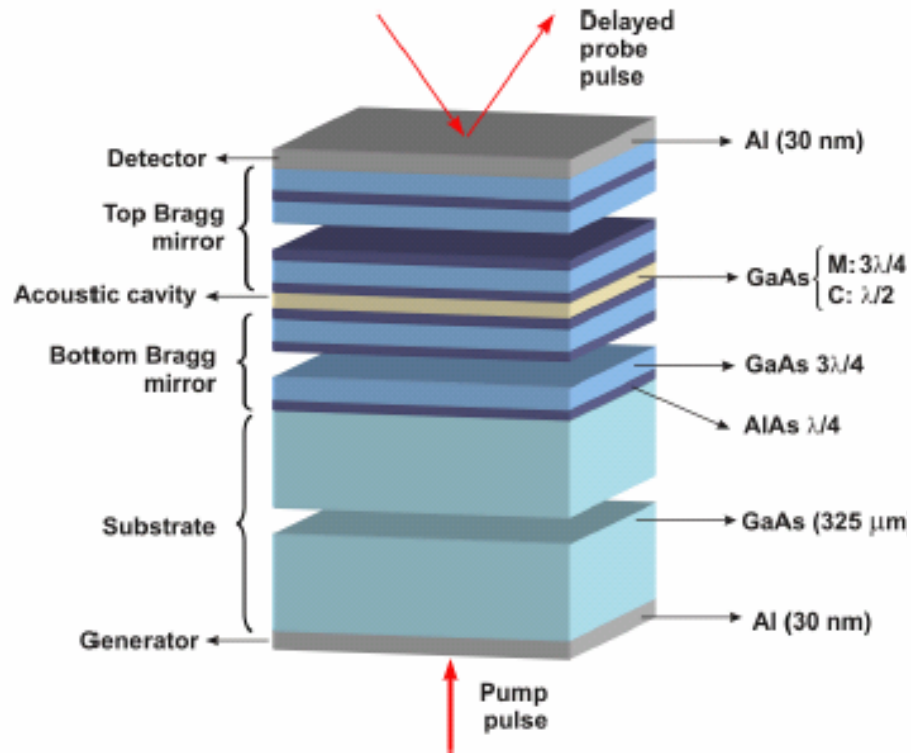
IUMRS-ICEM 2008, Sydney, Australia  
July 28 – August 1, 2008

# Thermoelectrics — Figure of Merit

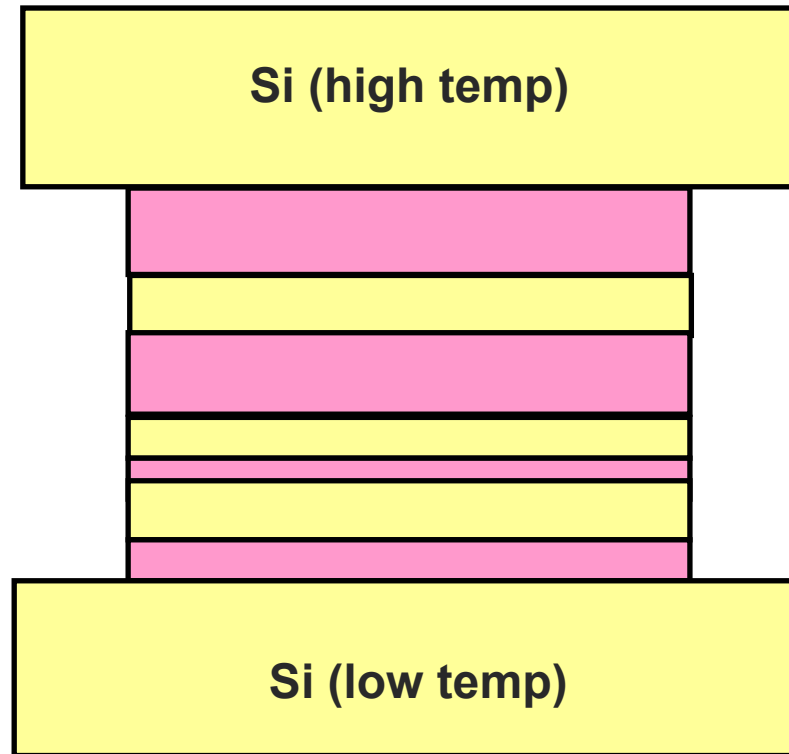


$$Z = \frac{S^2 \sigma}{k}$$

# Ballistic Phonon Transport ?

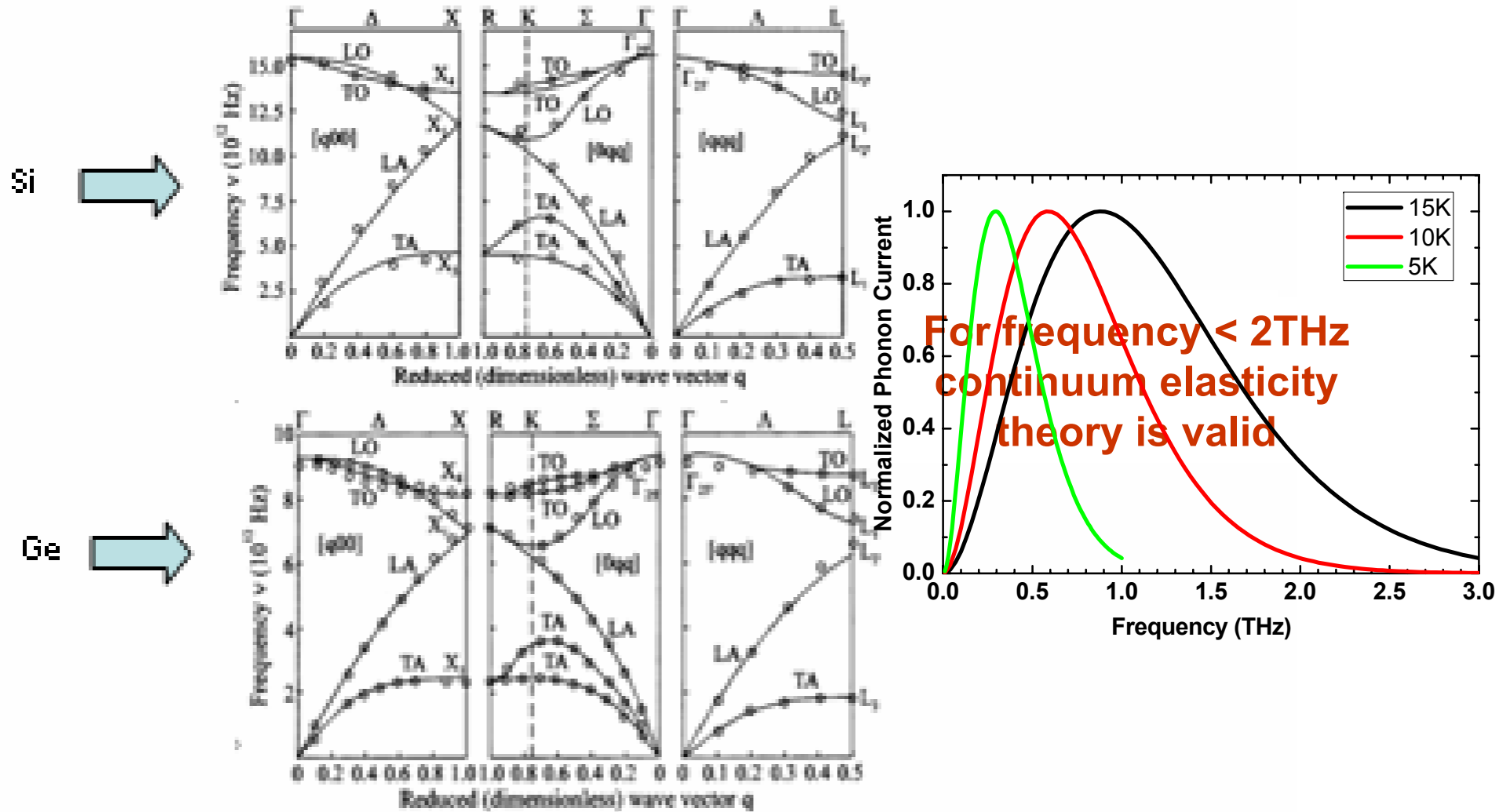


# Aperiodic Superlattices for Controlling Ballistic Transport ?

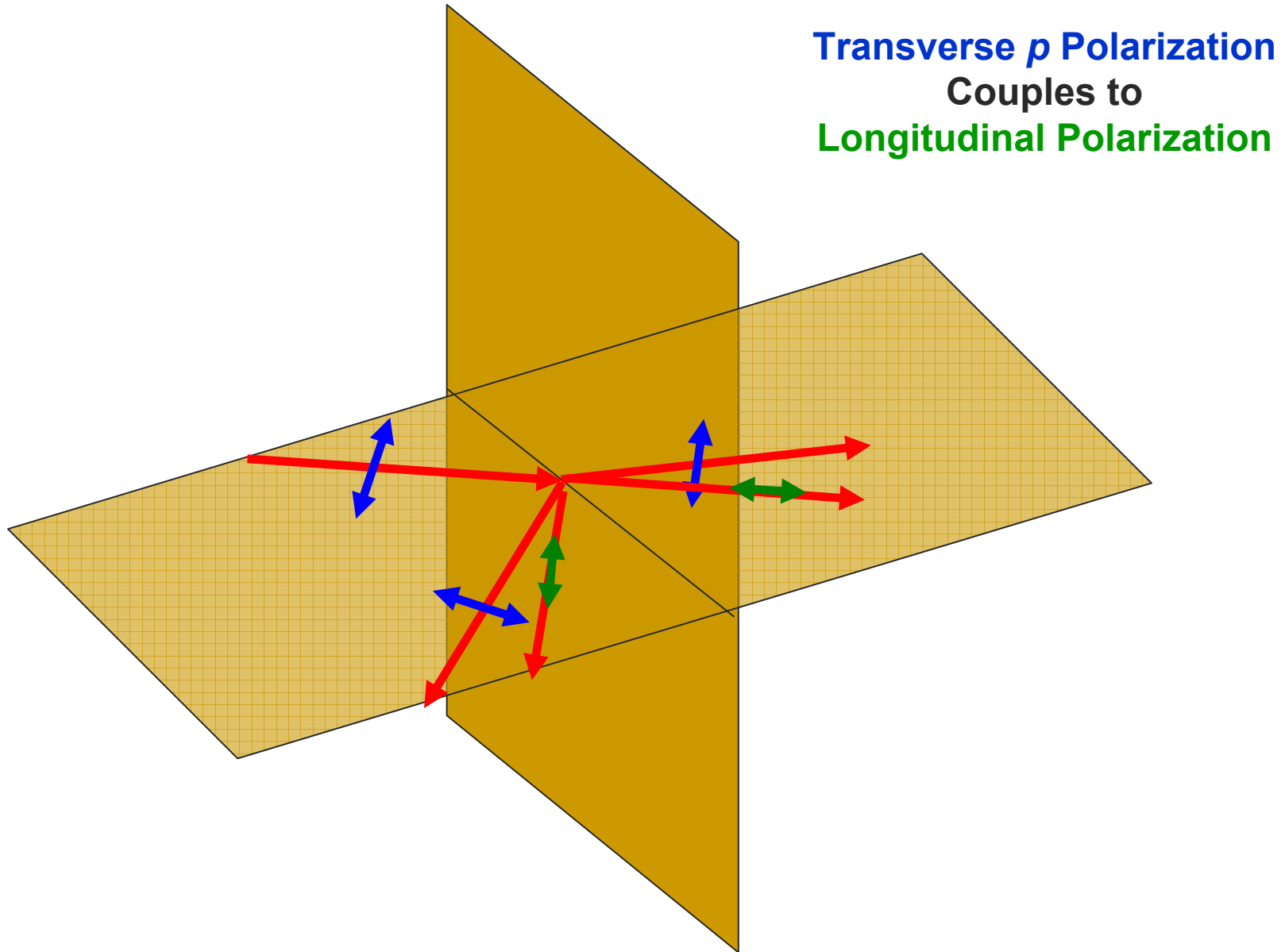


- **Can we design a reflector :**
  - **broad angle**
  - **broadband**
  - **polarization independent**
- **Can it be better than a phononic-crystal ?**

# Continuum Elasticity

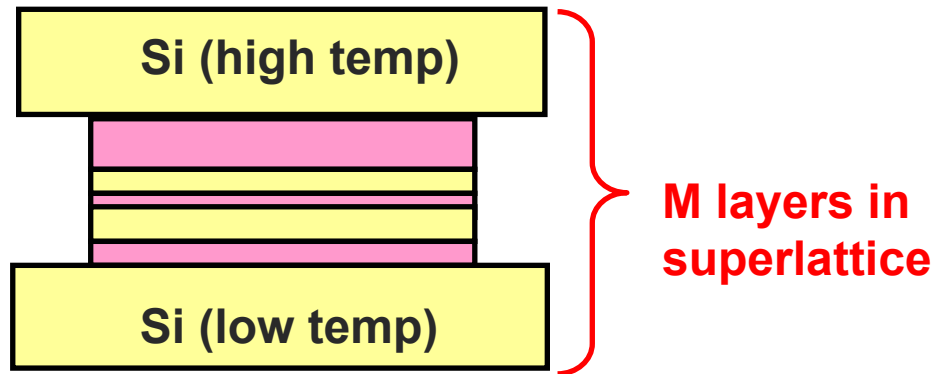


# Mode Coupling



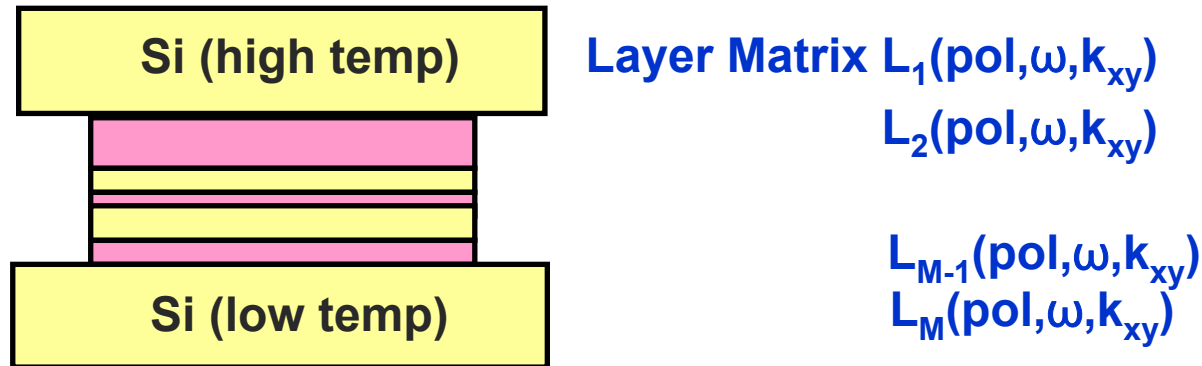
# Needle Optimization

Existing structure:  $M$  layer in the superlattice



- M. Agrawal and P. Peumans, *Opt. Express* **15**, 9715 (2007)  
B. T. Sullivan and J. A. Dobrowolski, *Appl. Opt.* **35**, 5484 (1996)  
A. V. Tikhonravov et al., *Appl. Opt.* **35**, 5493 (1996)

# Needle Optimization



**Coupled Transverse  $p$  Polarization and Longitudinal Polarization**

**Layer Matrix  $\rightarrow$  4 x 4 matrix**

**Transverse  $s$  Polarization**

**Layer Matrix  $\rightarrow$  4 x 4 matrix**

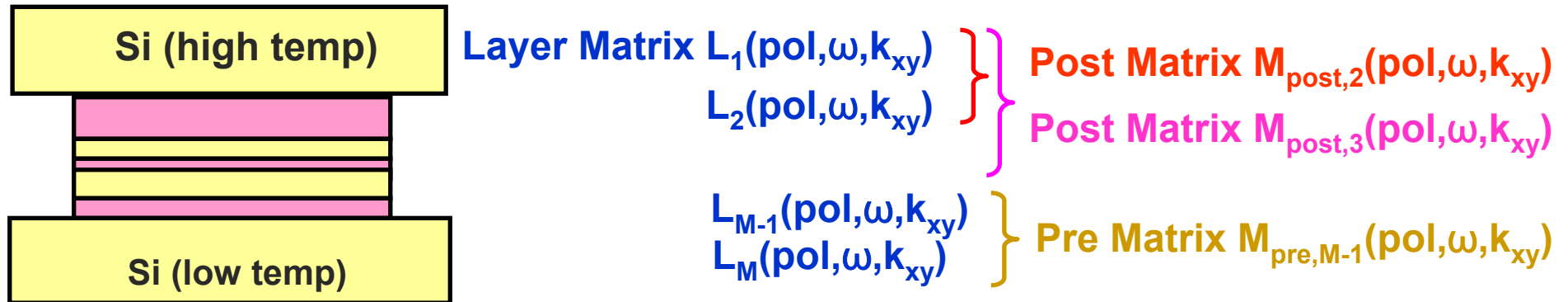
M. Agrawal and P. Peumans, *Opt. Express* **15**, 9715 (2007)

B. T. Sullivan and J. A. Dobrowolski, *Appl. Opt.* **35**, 5484 (1996)

A. V. Tikhonravov et al., *Appl. Opt.* **35**, 5493 (1996)

# Needle Optimization

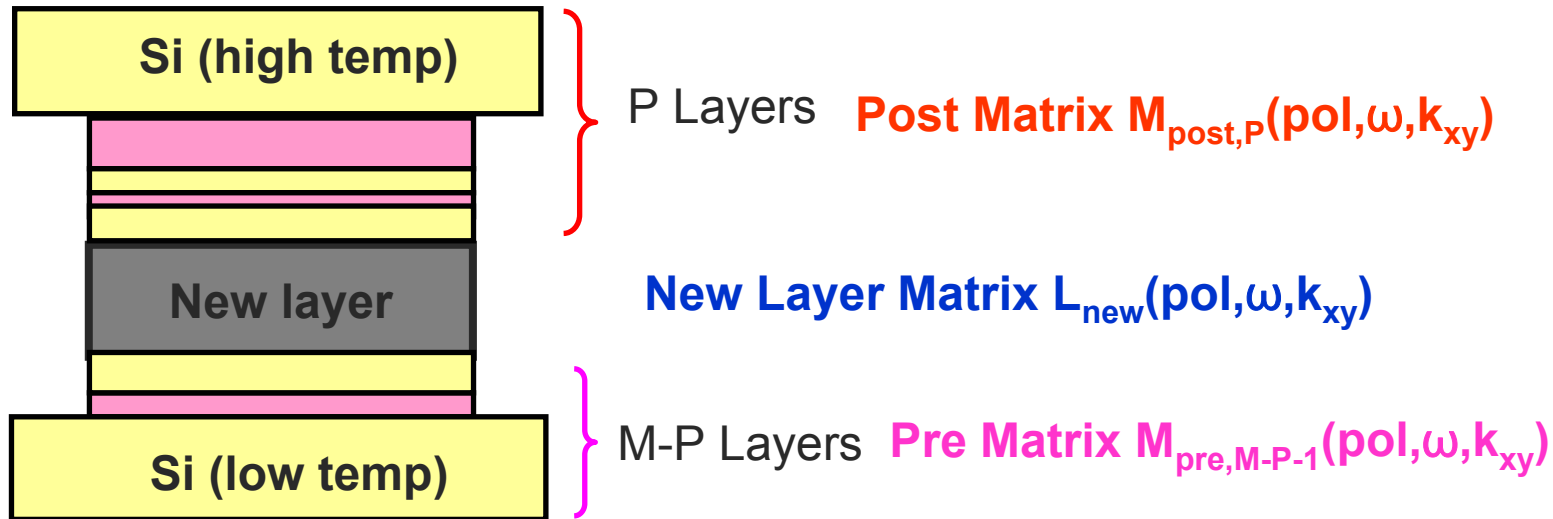
Trade-off: computation time vs memory



Now insert new layer after  $P$  top layers

- M. Agrawal and P. Peumans, *Opt. Express* **15**, 9715 (2007)
- B. T. Sullivan and J. A. Dobrowolski, *Appl. Opt.* **35**, 5484 (1996)
- A. V. Tikhonravov et al., *Appl. Opt.* **35**, 5493 (1996)

# Needle Optimization



This new structure can now be analyzed very efficiently

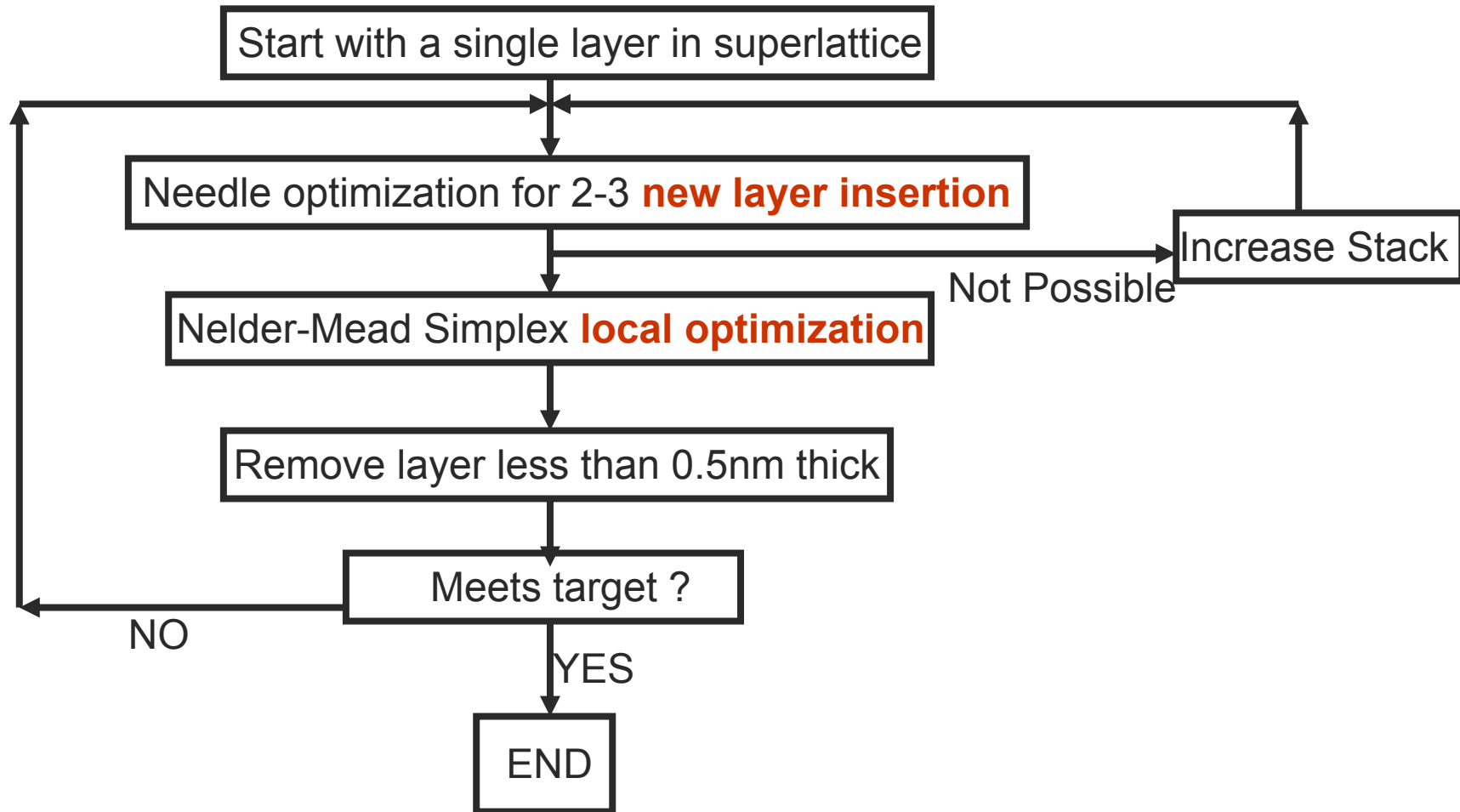
$$M_{\text{post},P}(\text{pol},\omega,k_{xy}) \times L_{\text{new}}(\text{pol},\omega,k_{xy}) \times M_{\text{pre},M-P-1}(\text{pol},\omega,k_{xy})$$

M. Agrawal and P. Peumans, *Opt. Express* **15**, 9715 (2007)

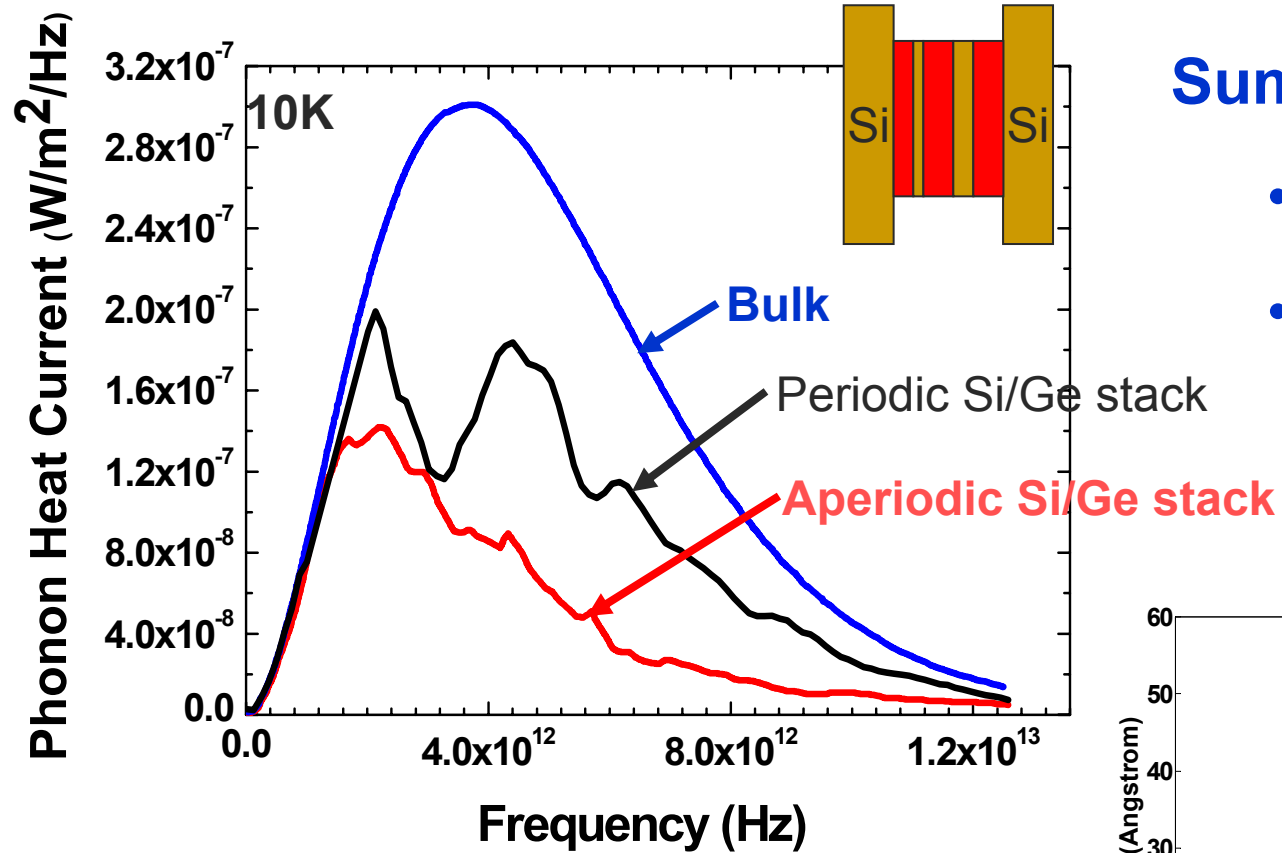
B. T. Sullivan and J. A. Dobrowolski, *Appl. Opt.* **35**, 5484 (1996)

A. V. Tikhonravov et al., *Appl. Opt.* **35**, 5493 (1996)

# Typical Algorithm Used

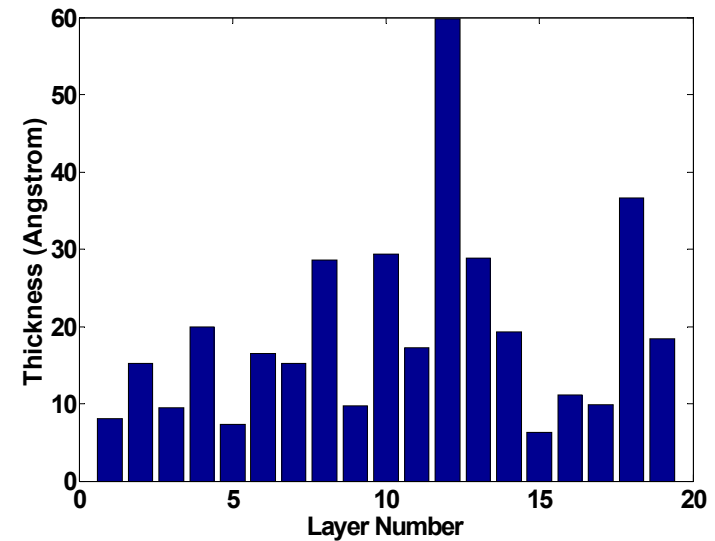


# Phonon Heat Current

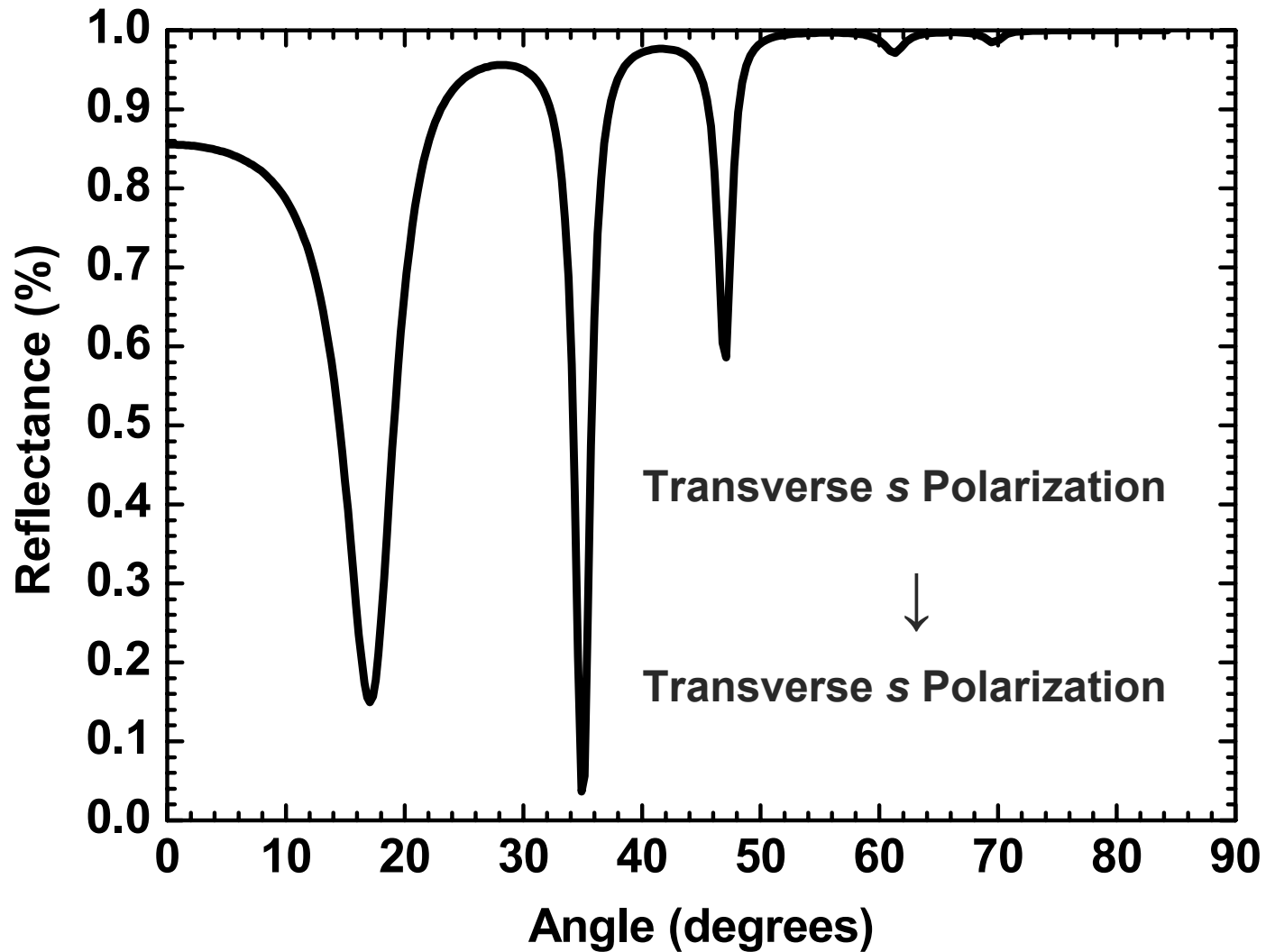


Summed over

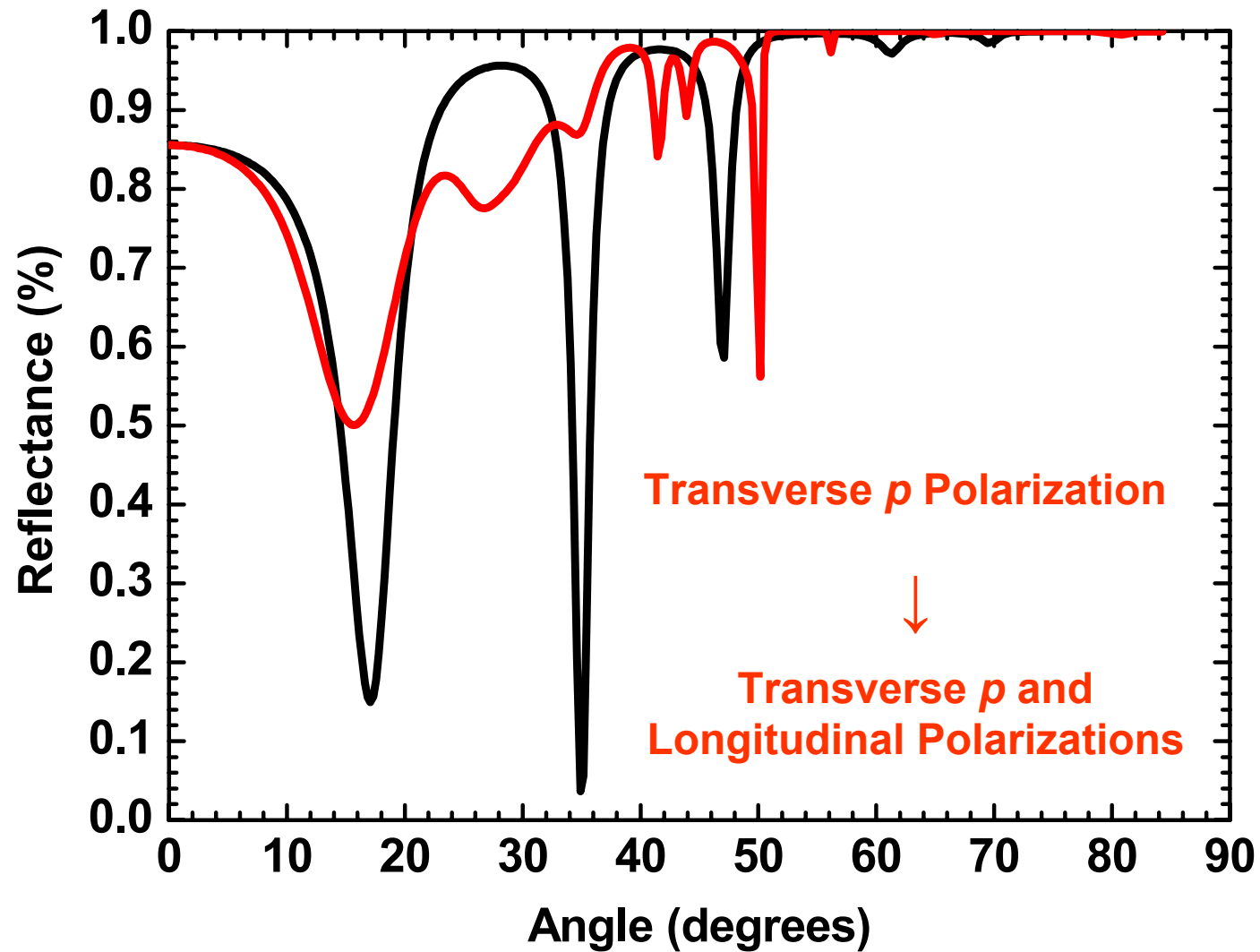
- all polarizations
- all angles



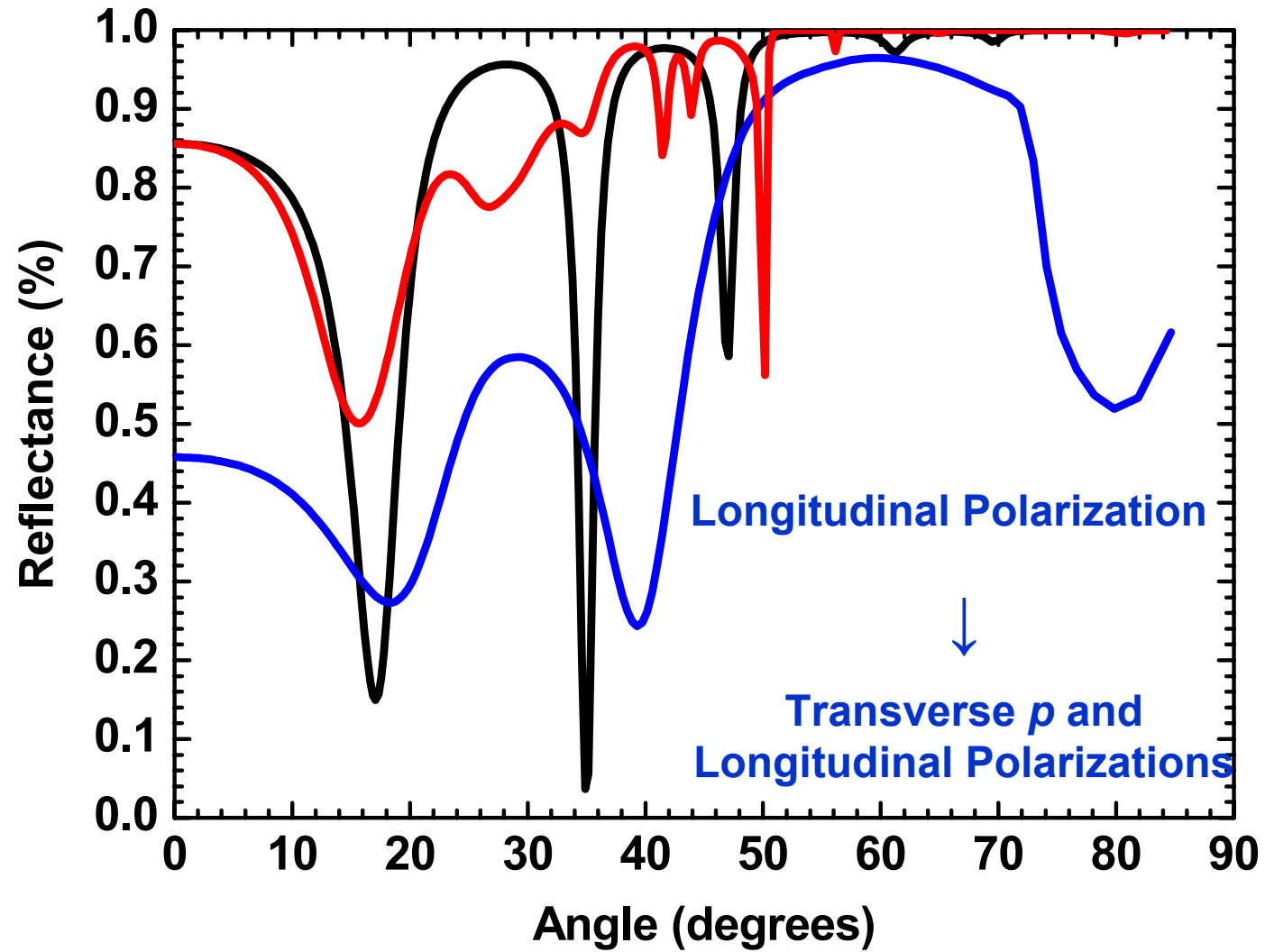
# Reflectance



# Reflectance



# Reflectance



# Conclusions

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- Under ballistic transport regime
  - Aperiodic structure can perform significantly better than periodic structures
- Broadband, broad-angle, polarization independent acoustic reflectors
- A straightforward design and optimization scheme for 1D phononic structures
  - Needle optimization