Ultrafast Lattice-Bonding Dynamics in Tellurium

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How to monitor material dynamics?

How to monitor material dynamics?

reflectivity, transmission

How to monitor material dynamics?

reflectivity, transmission

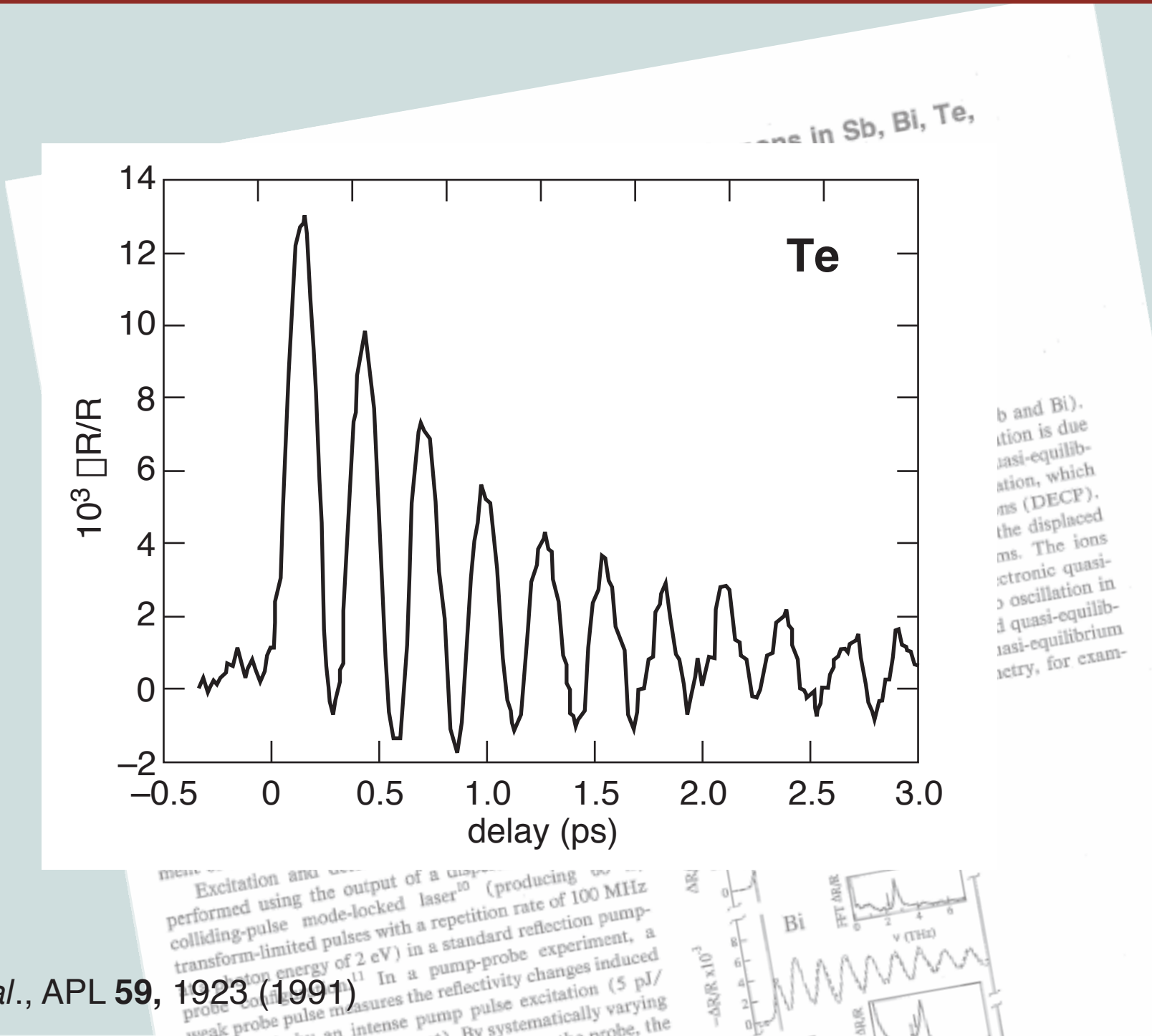
ellipsometry

How to monitor material dynamics?

reflectivity, transmission

ellipsometry
- more complete picture of dynamics
- allows device design

INTRODUCTION



Cheng *et al*., APL **59,** 1923 (1991)

OUTLINE

Experimental technique

time-resolved dielectric function

Results

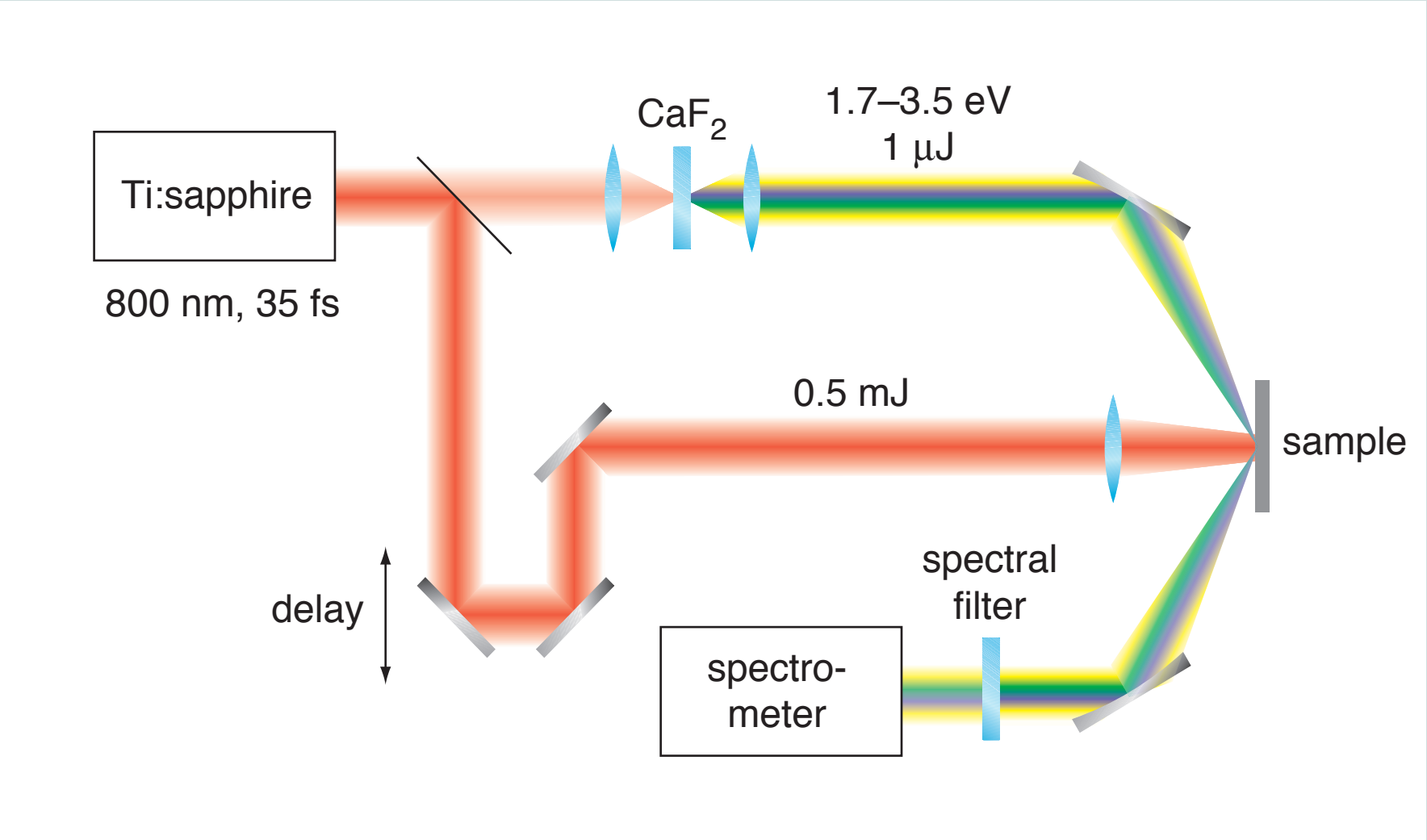
effects of coherent phonons on $\epsilon(\omega)$

Discussion

two-atom model

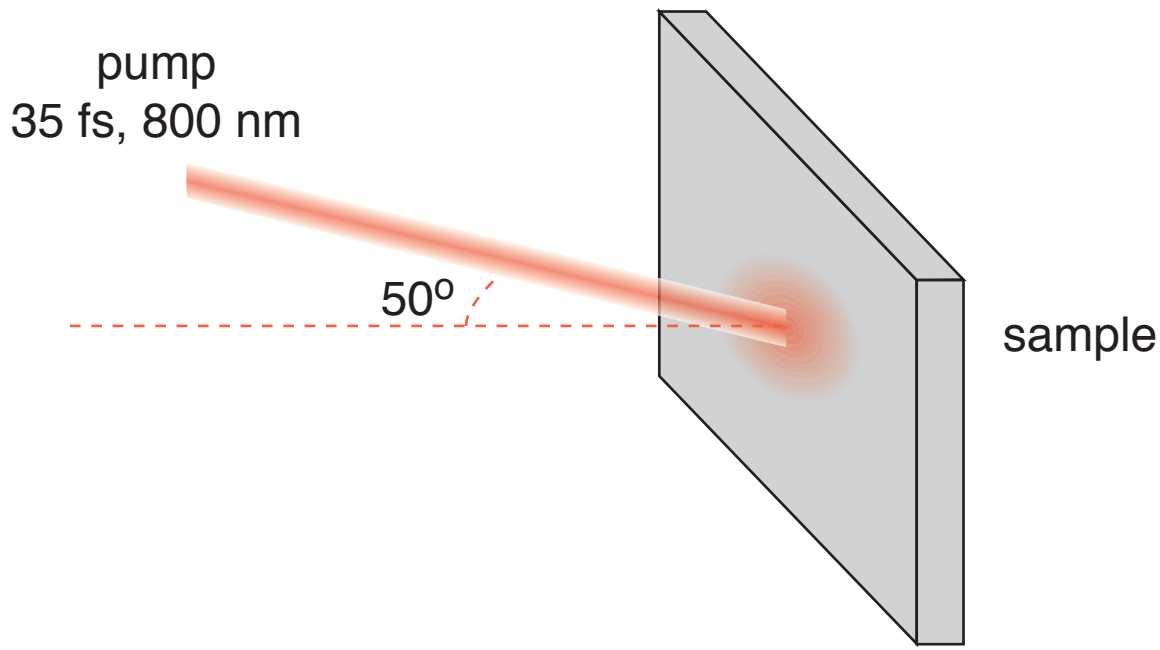
DFT calculations

Time-resolved ellipsometry

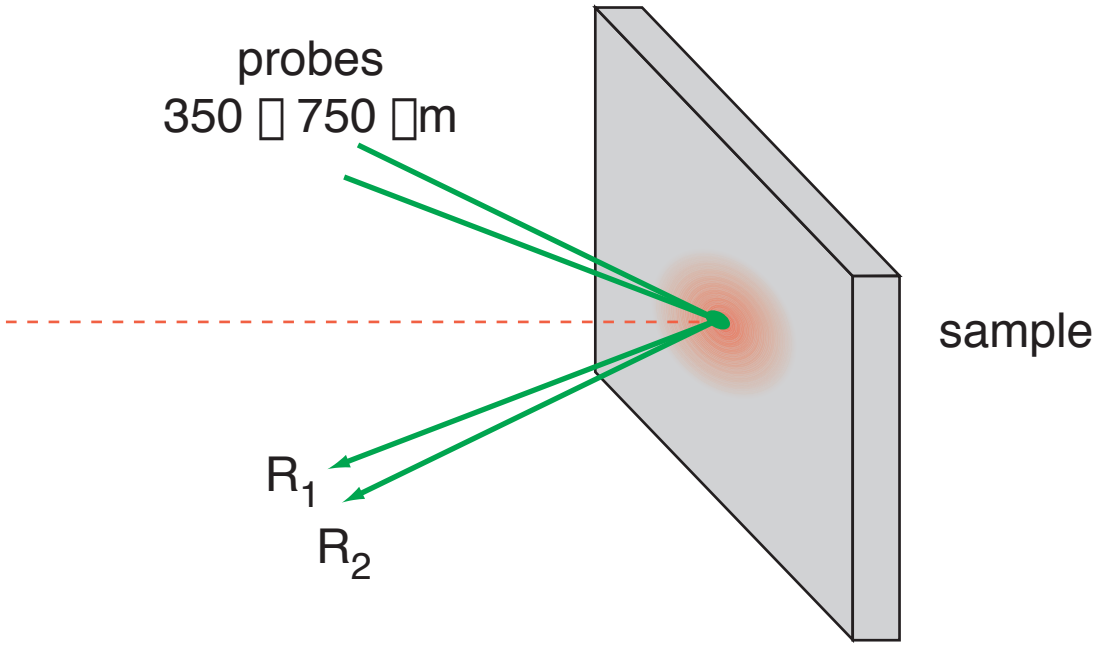


White-light pump-probe setup

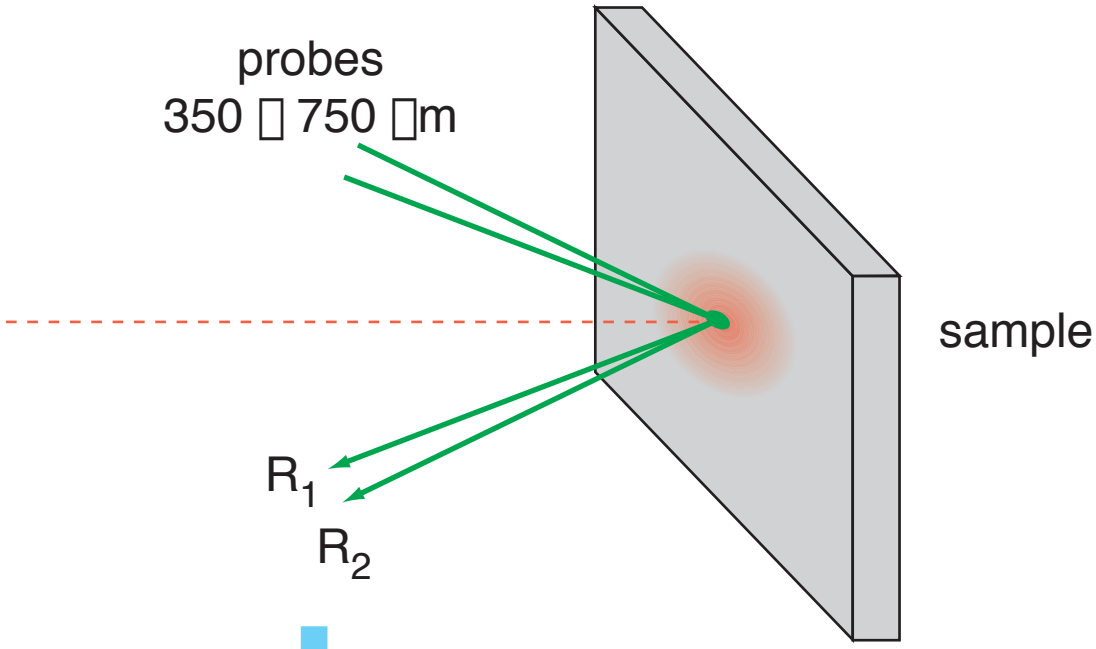
Time-resolved ellipsometry



Time-resolved ellipsometry

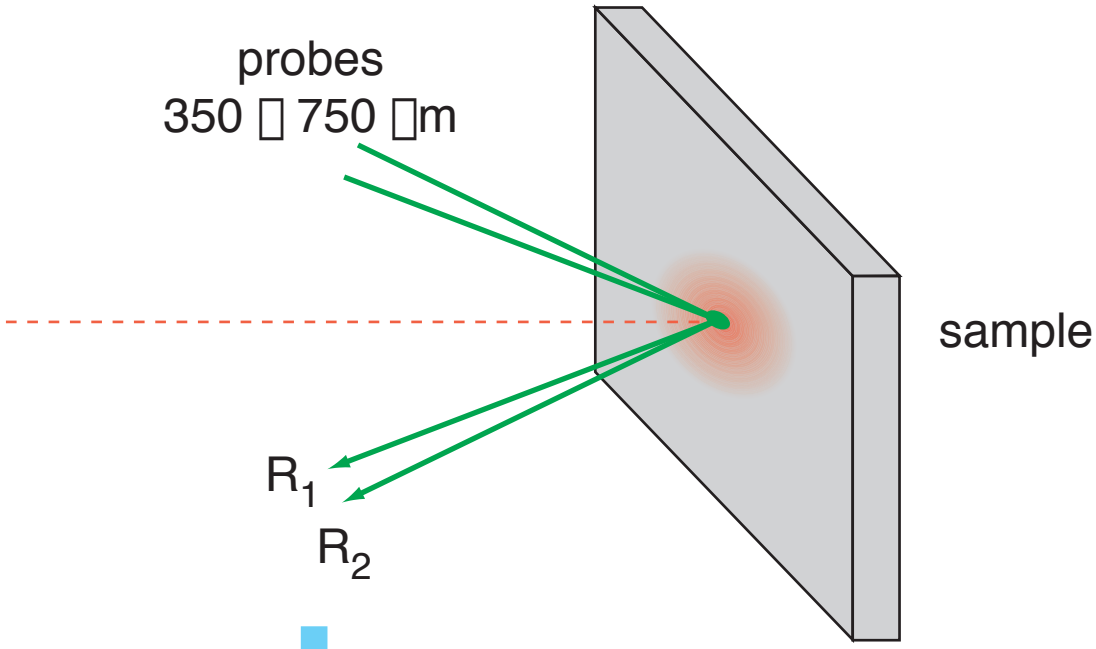


Time-resolved ellipsometry



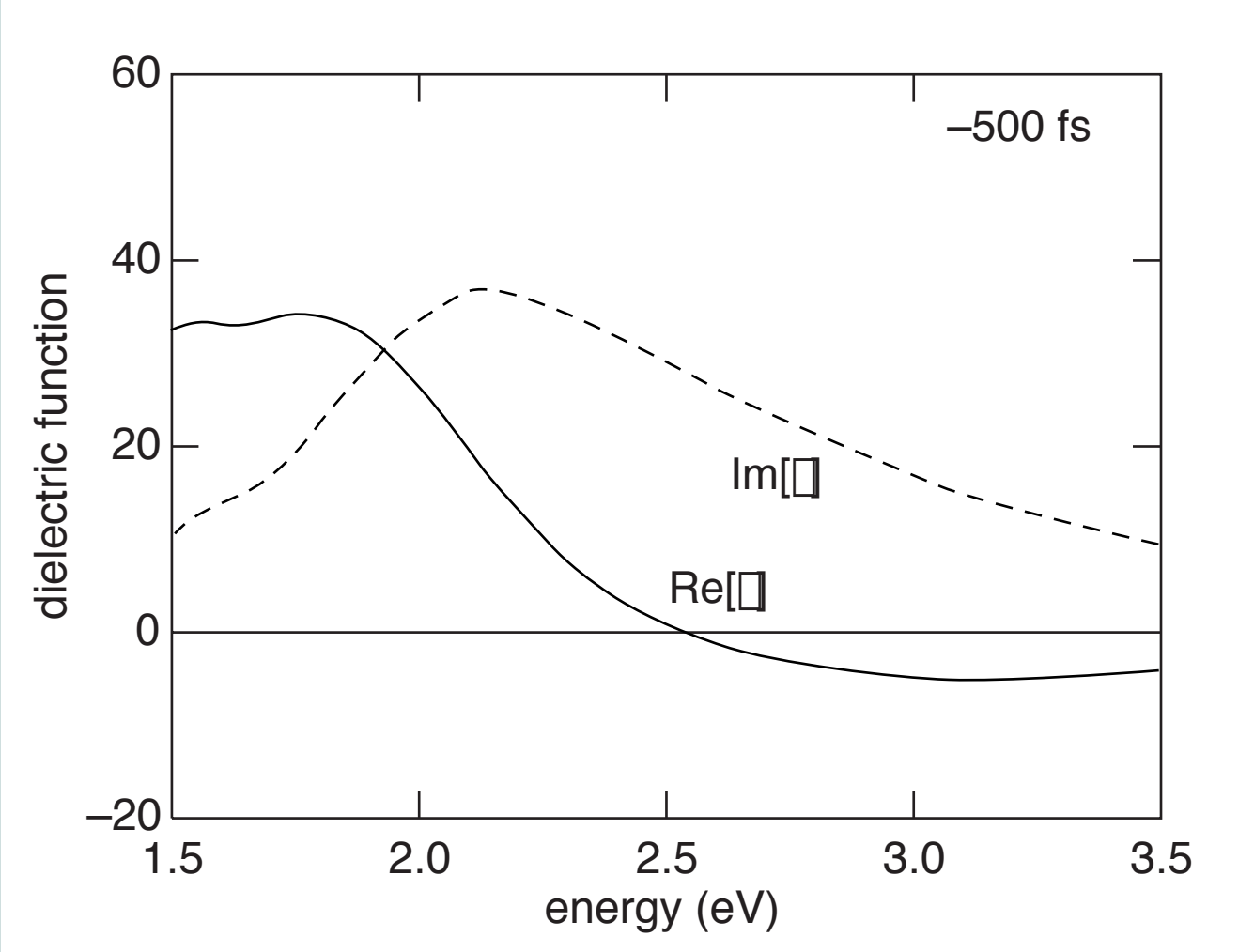
Fresnel equations

Time-resolved ellipsometry

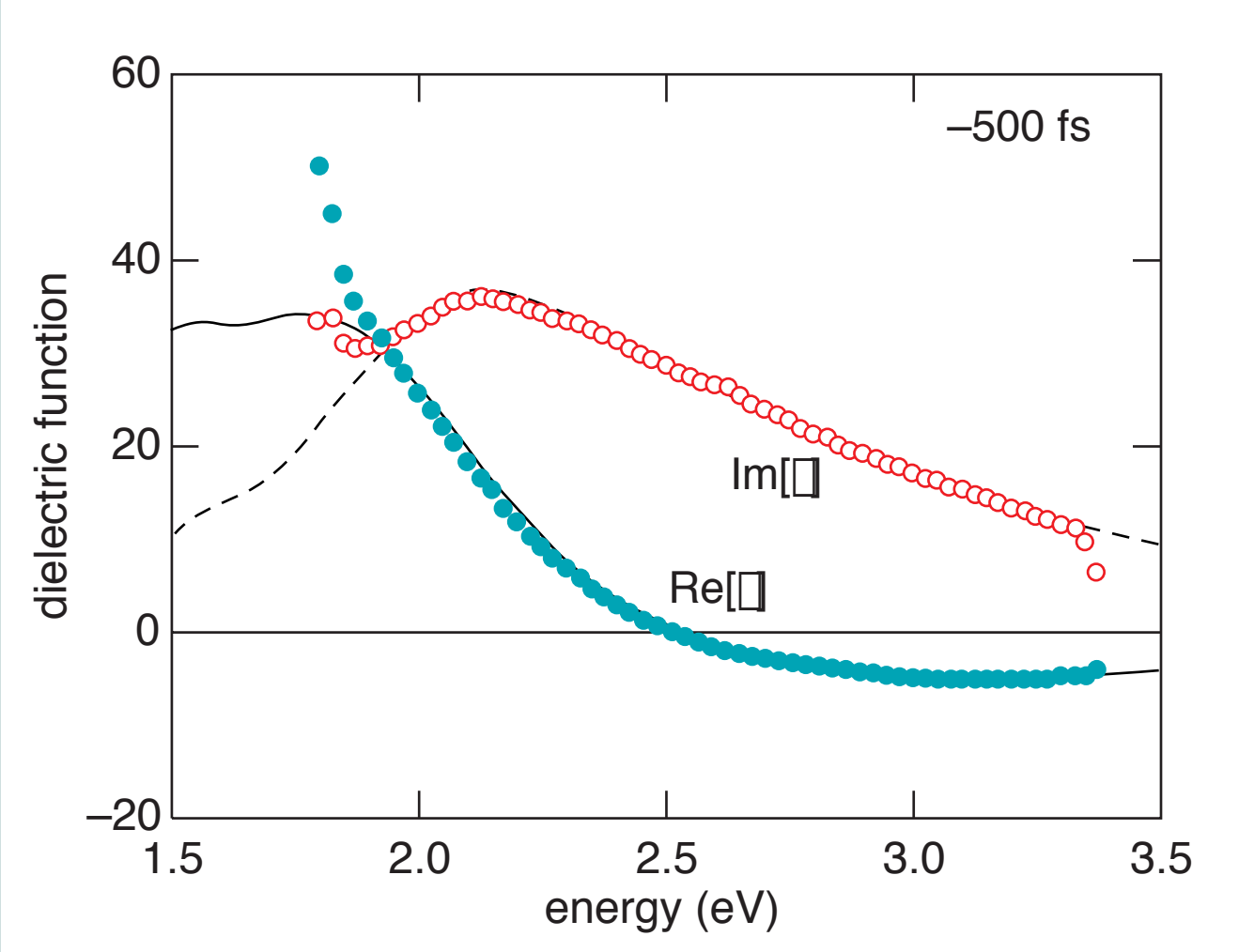


Fresnel equations → Re[□(□)] Im[□(□)]

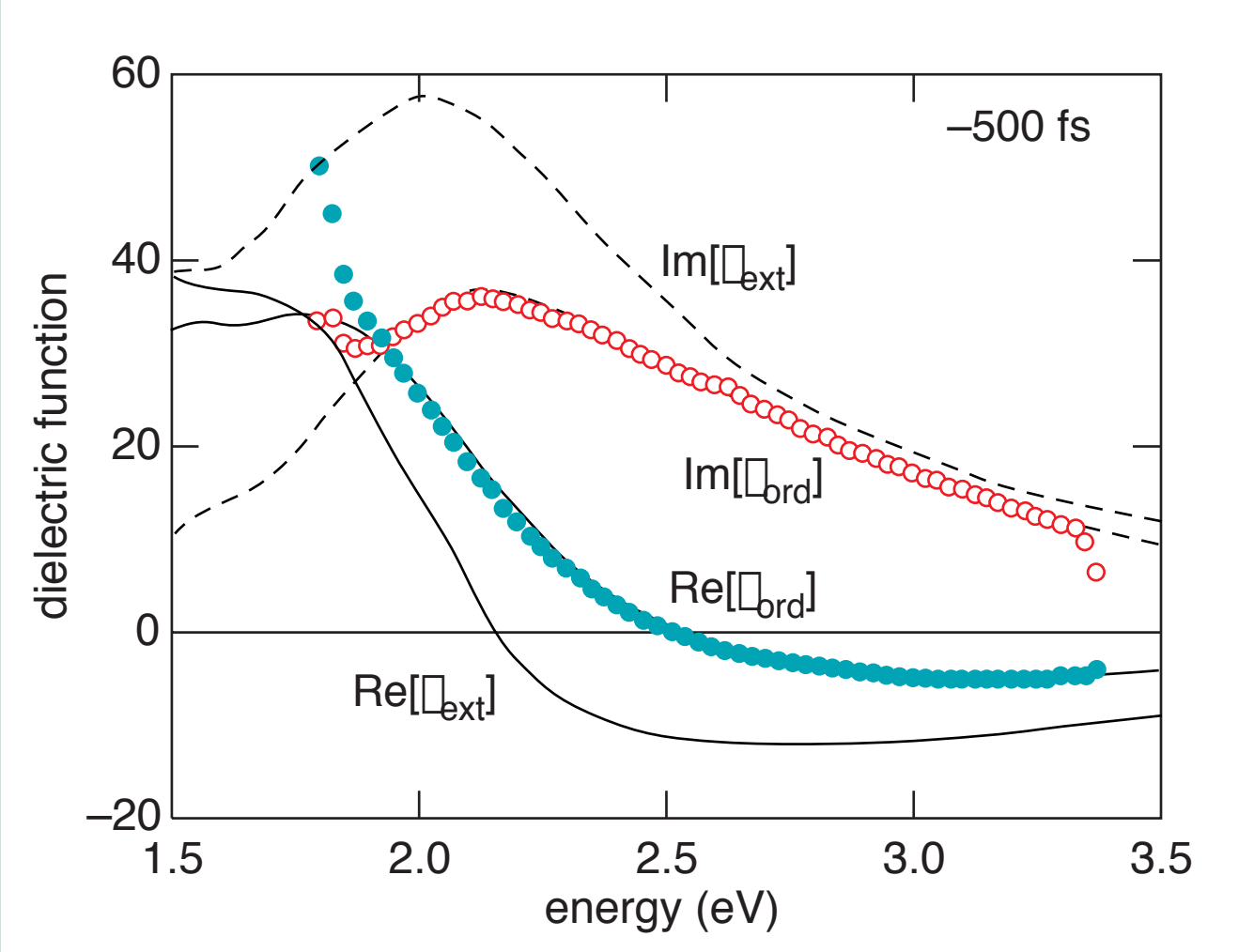
RESULTS


60
40
20
0
–20
dielectric function
–500 fs
Im[]
Re[]
1.5
2.0
2.5
3.0
3.5
energy (eV)

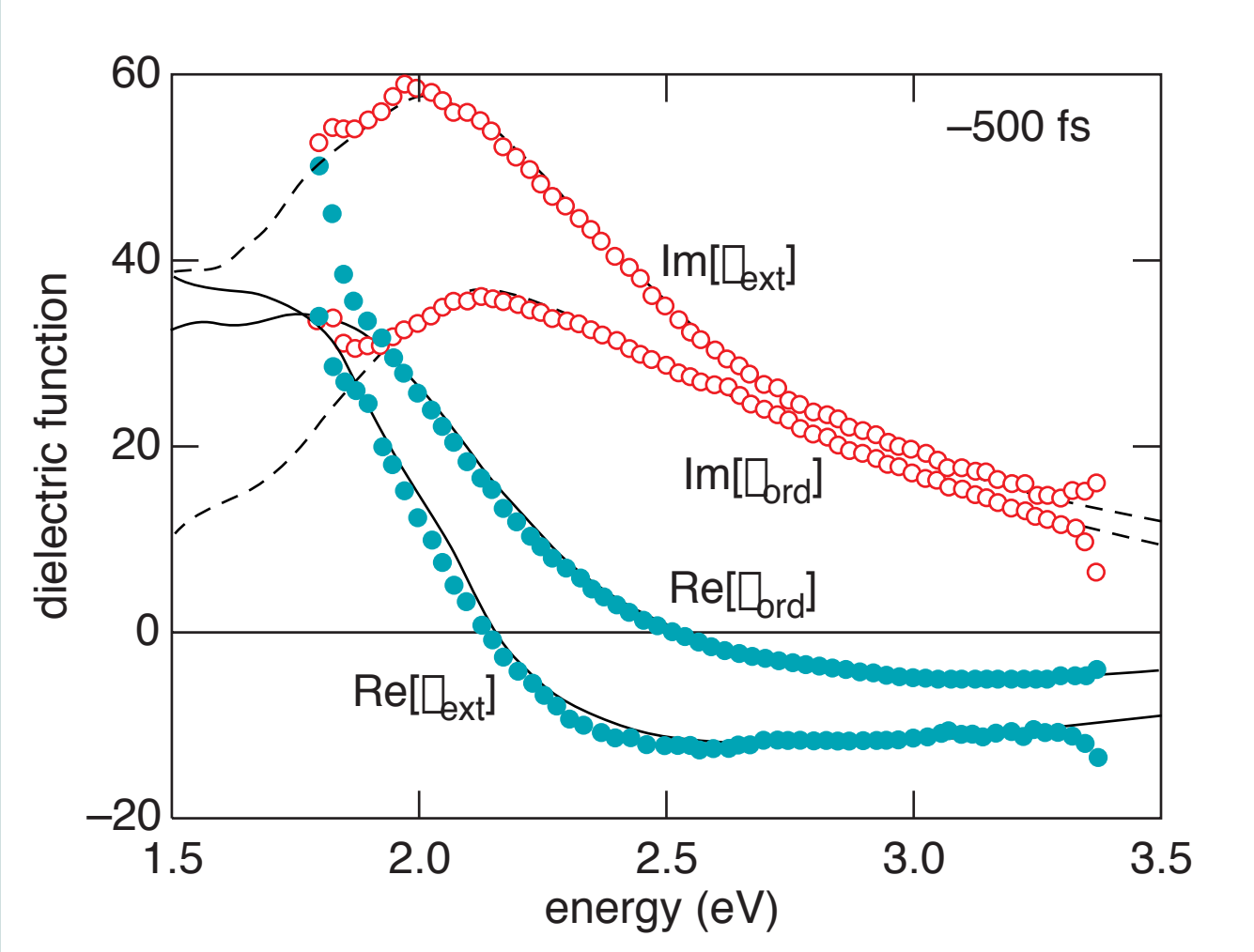
RESULTS


60
40
20
0
–20
1.5
2.0
2.5
3.0
3.5
energy (eV)
dielectric function
–500 fs
Im[□]
Re[□]

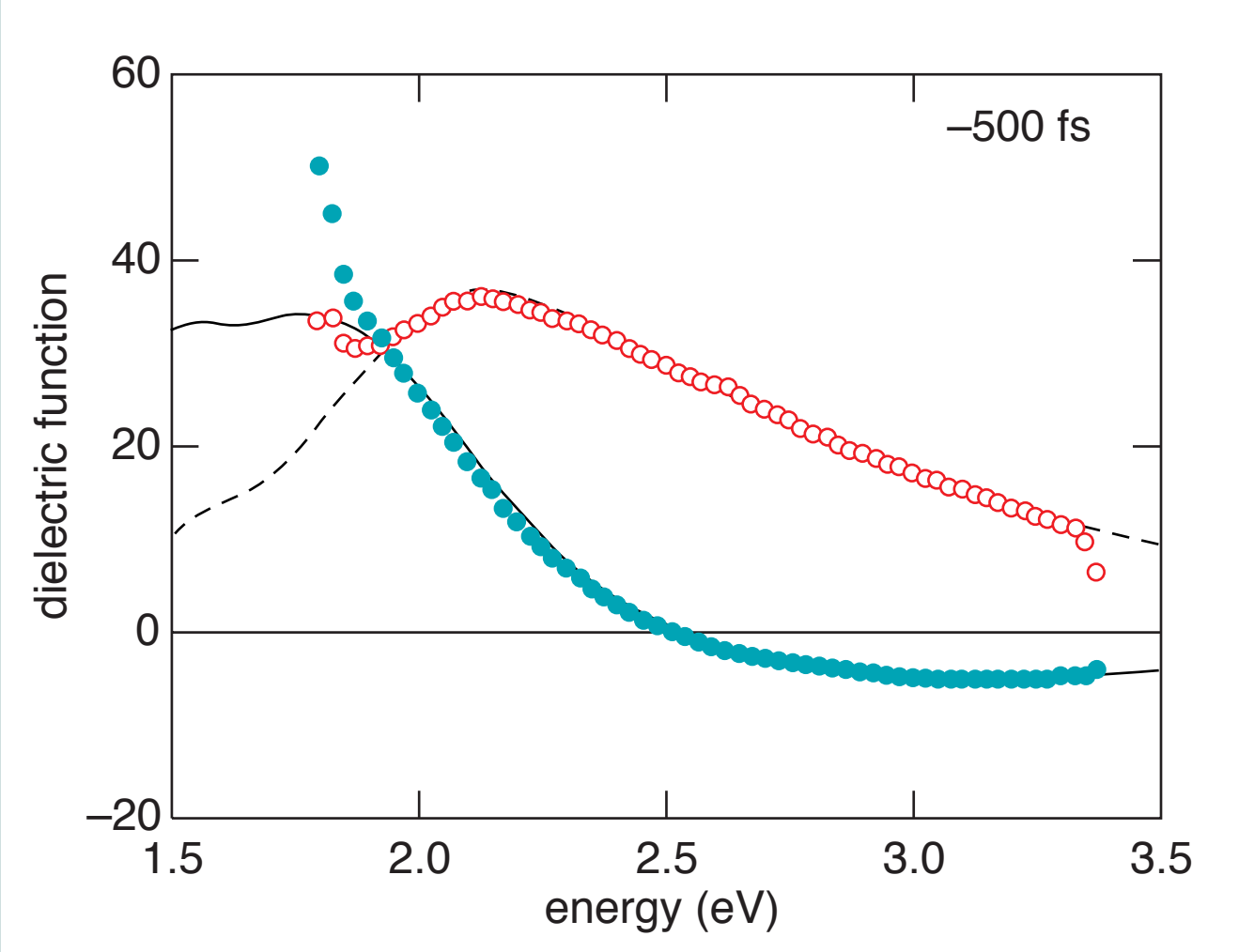
RESULTS


60
40
20
0
–20
1.5
2.0
2.5
3.0
3.5
energy (eV)
dielectric function
–500 fs
Im[εext]
Im[εord]
Re[εord]
Re[εext]

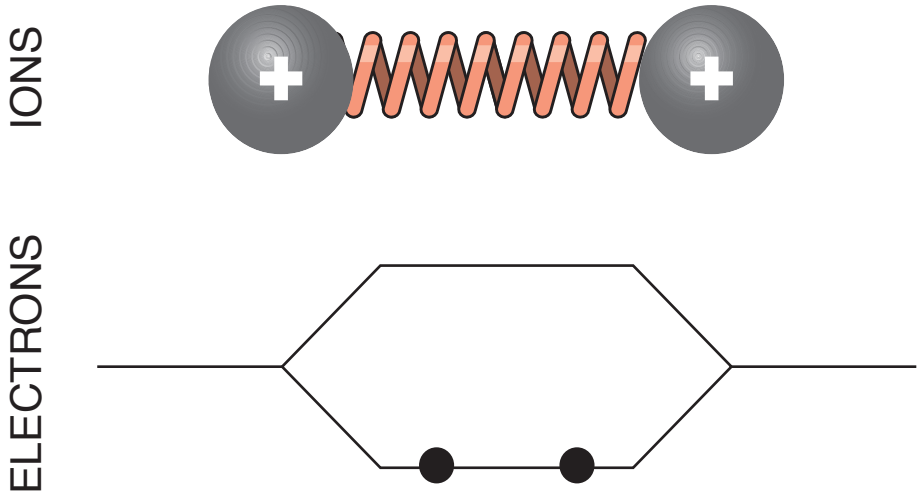
RESULTS


60
40
20
0
–20
1.5
2.0
2.5
3.0
3.5
energy (eV)
dielectric function
–500 fs
Im[εext]
Im[εord]
Re[εord]
Re[εext]

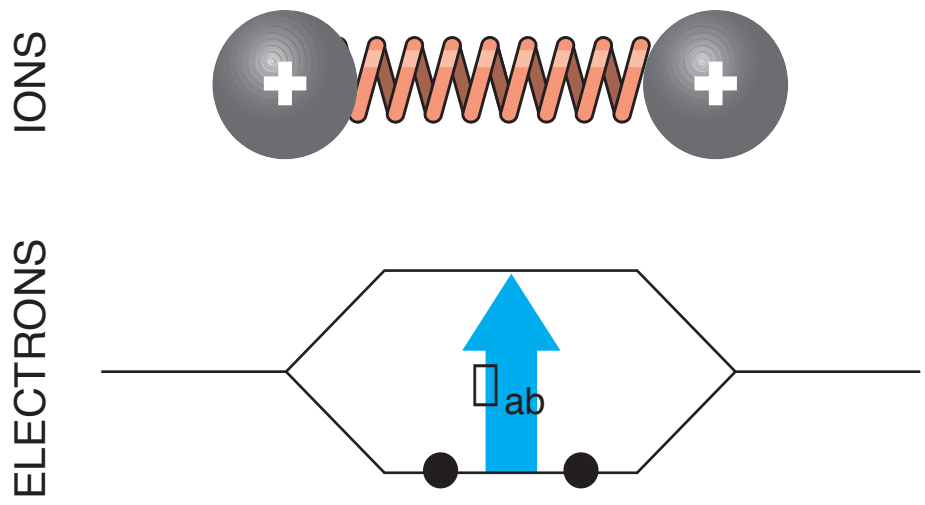
RESULTS


–500 fs
60
40
20
0
–20
dielectric function
1.5
2.0
2.5
3.0
3.5
energy (eV)

"Two-atom" model

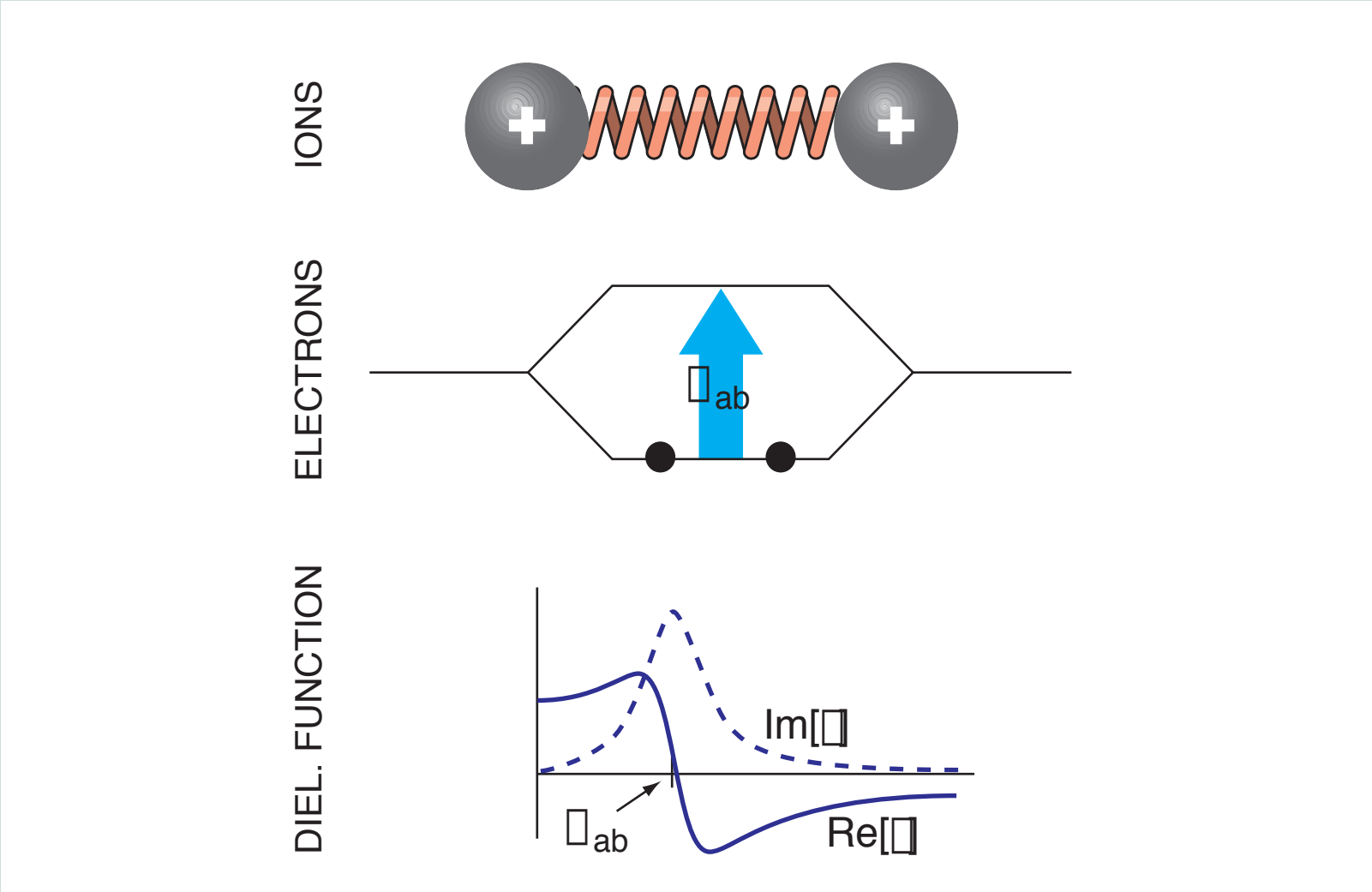


"Two-atom" model



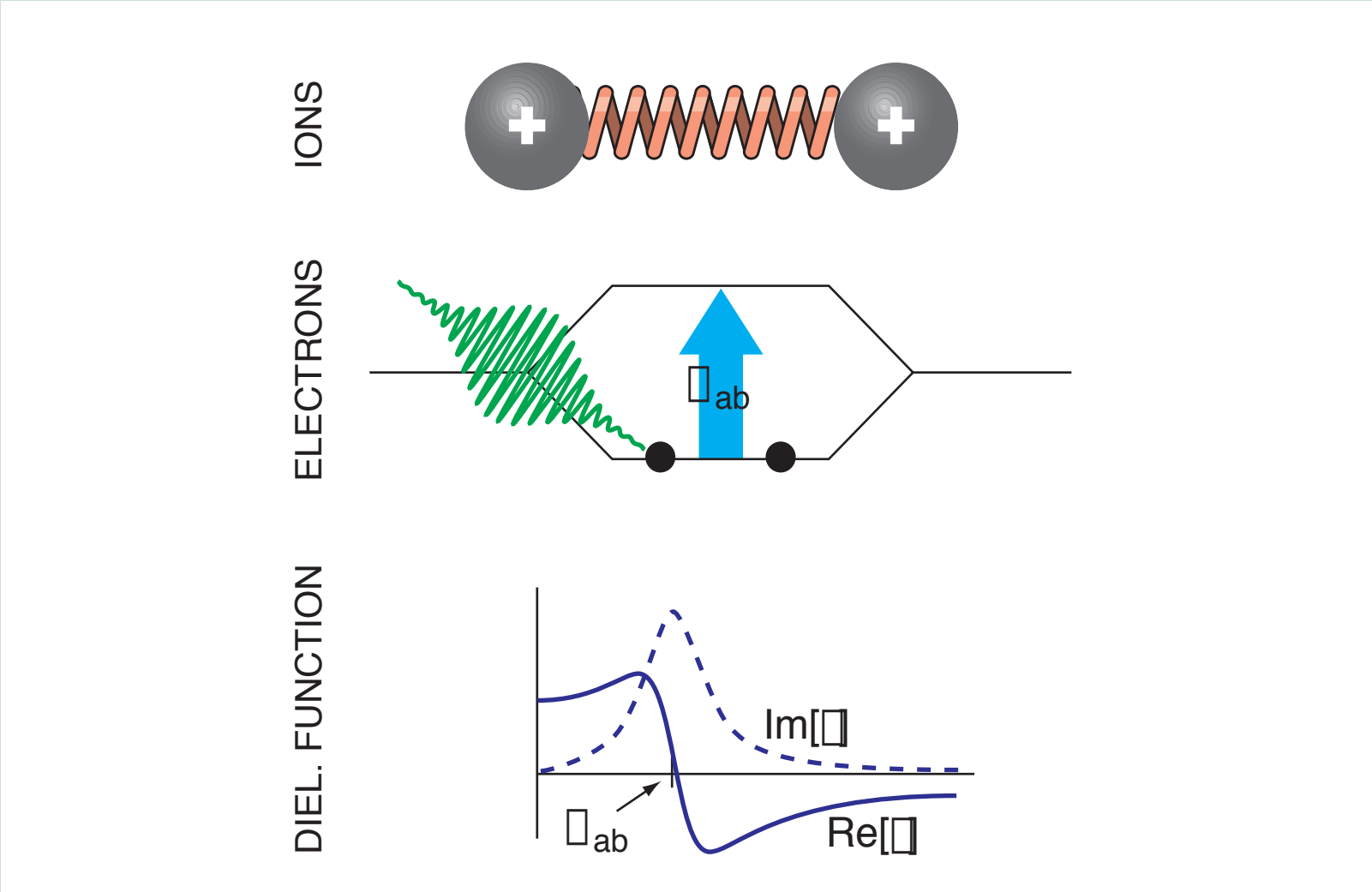
Bonding-antibonding splitting

"Two-atom" model



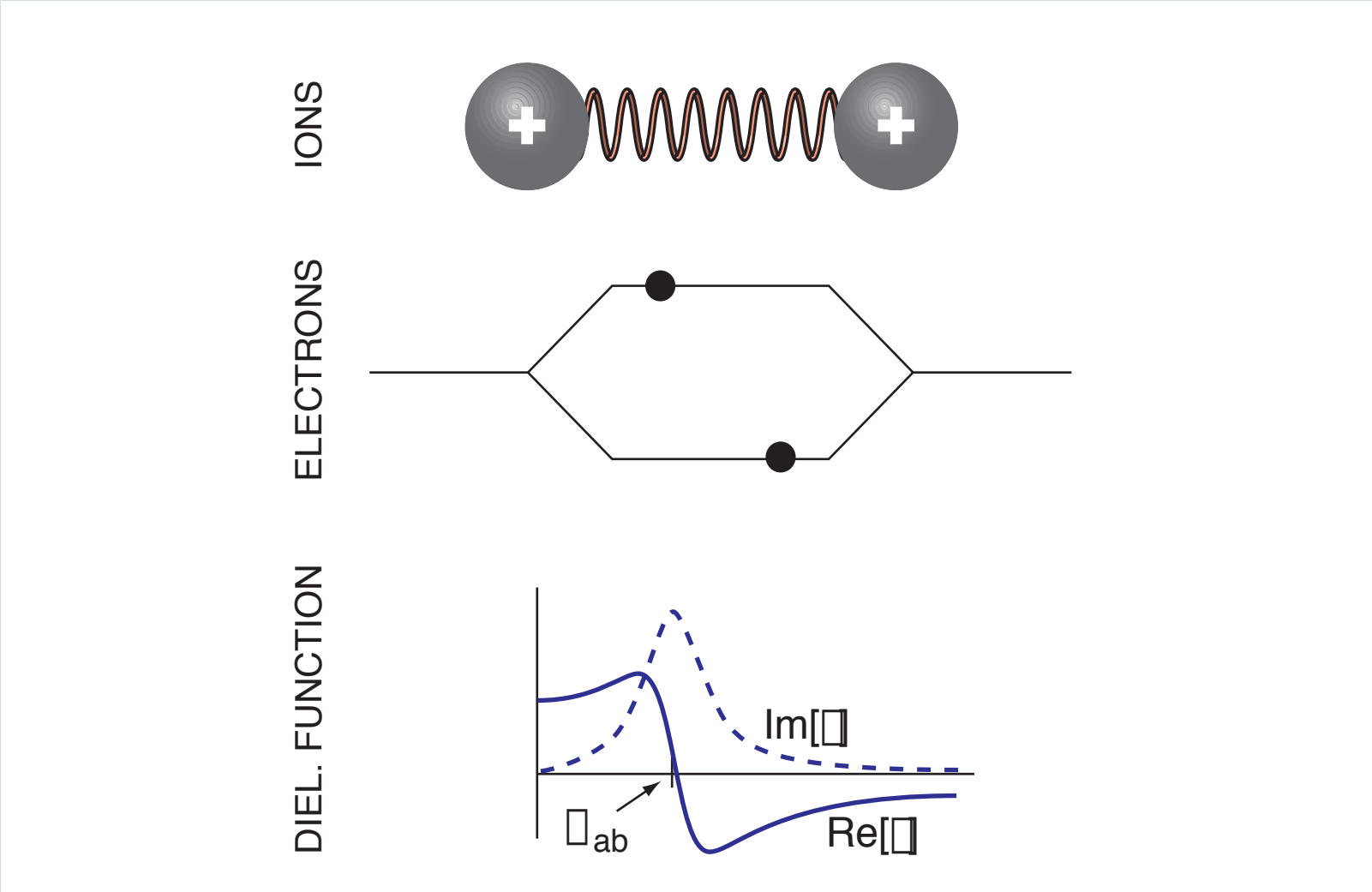
Lorentz oscillator model

"Two-atom" model



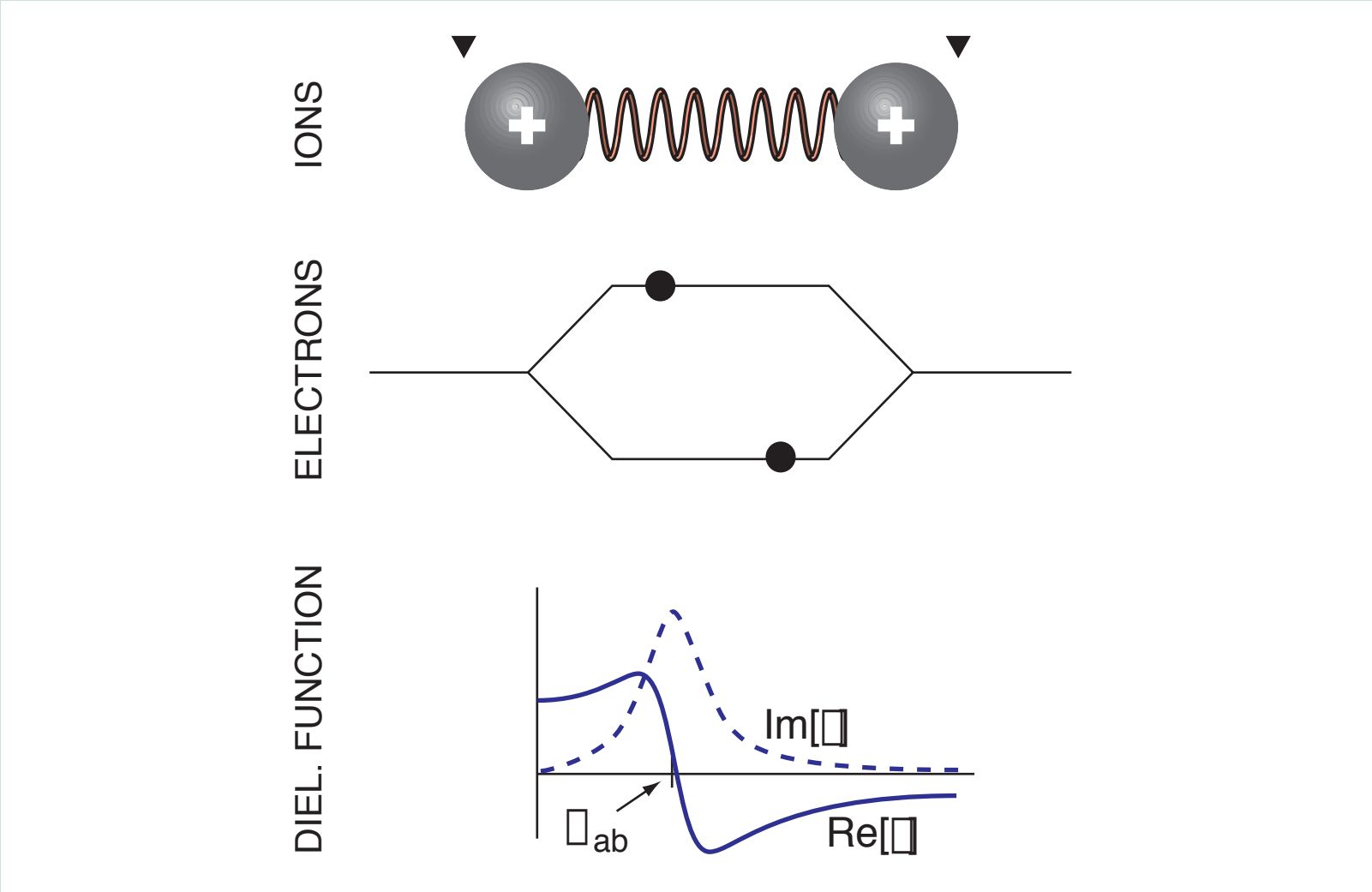
photon promotes an electron...

"Two-atom" model



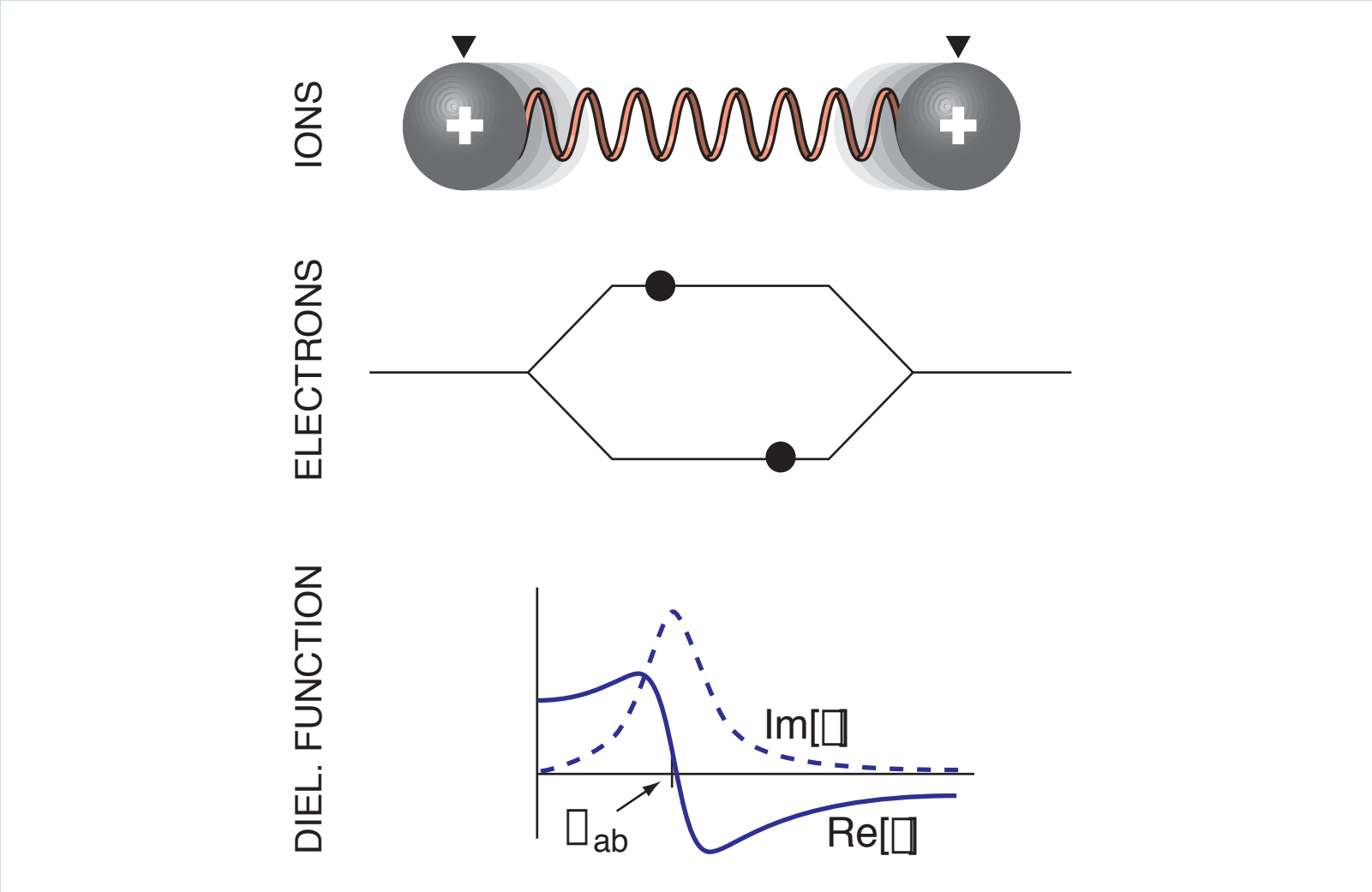
... weakening the bond...

"Two-atom" model



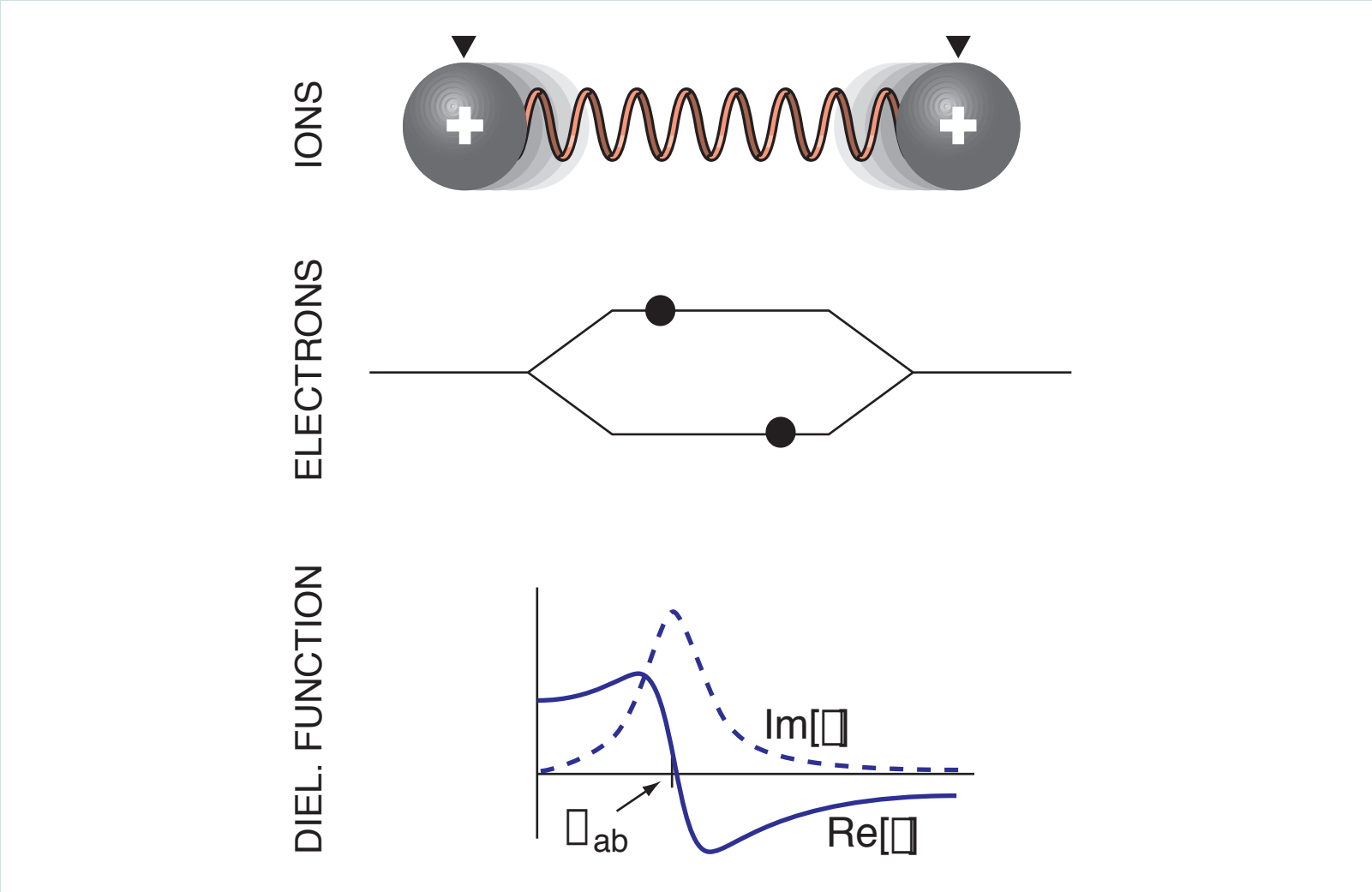
... establishing new equilibrium positions

"Two-atom" model



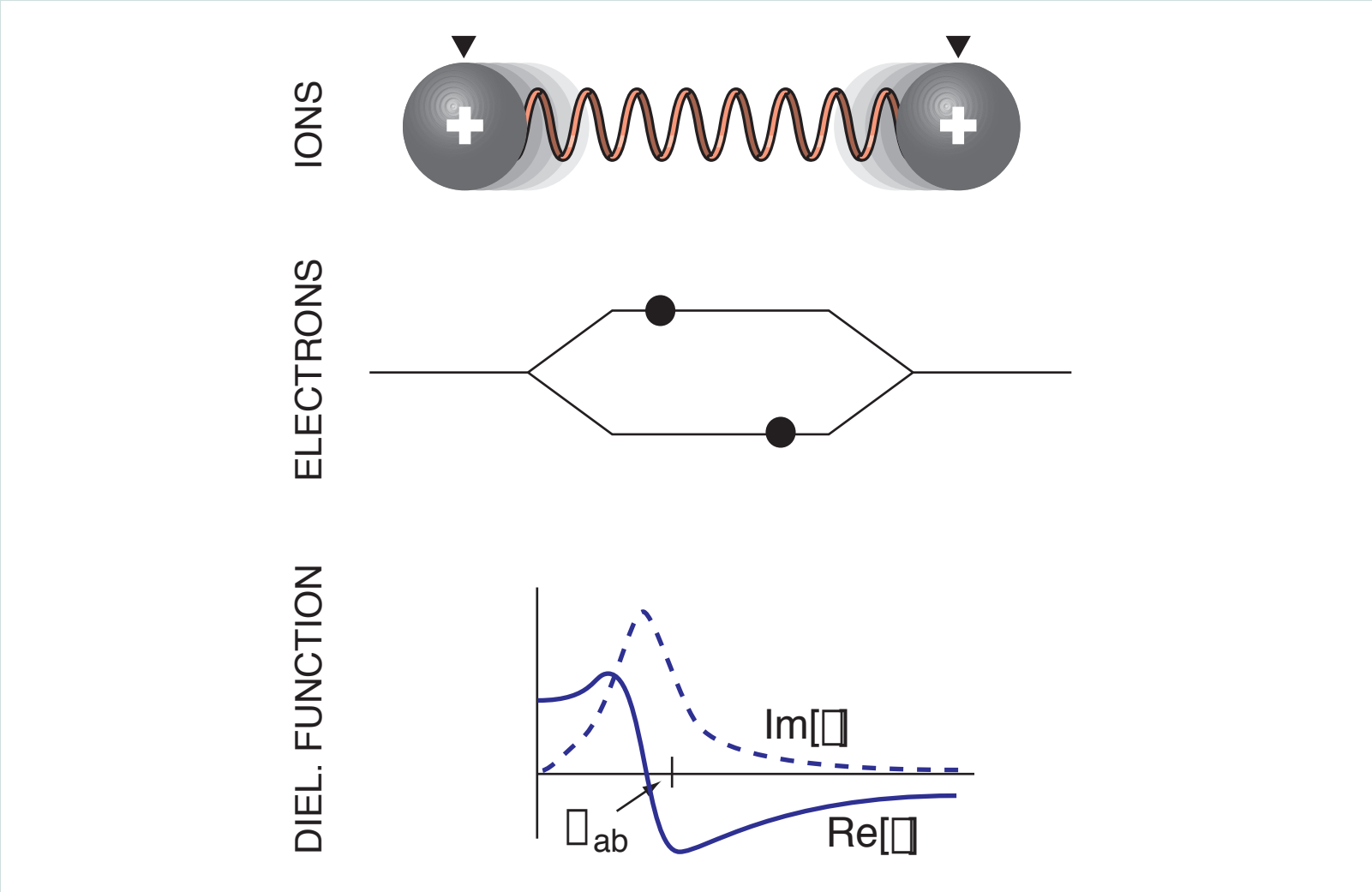
ions move to new equilibrium positions...

"Two-atom" model



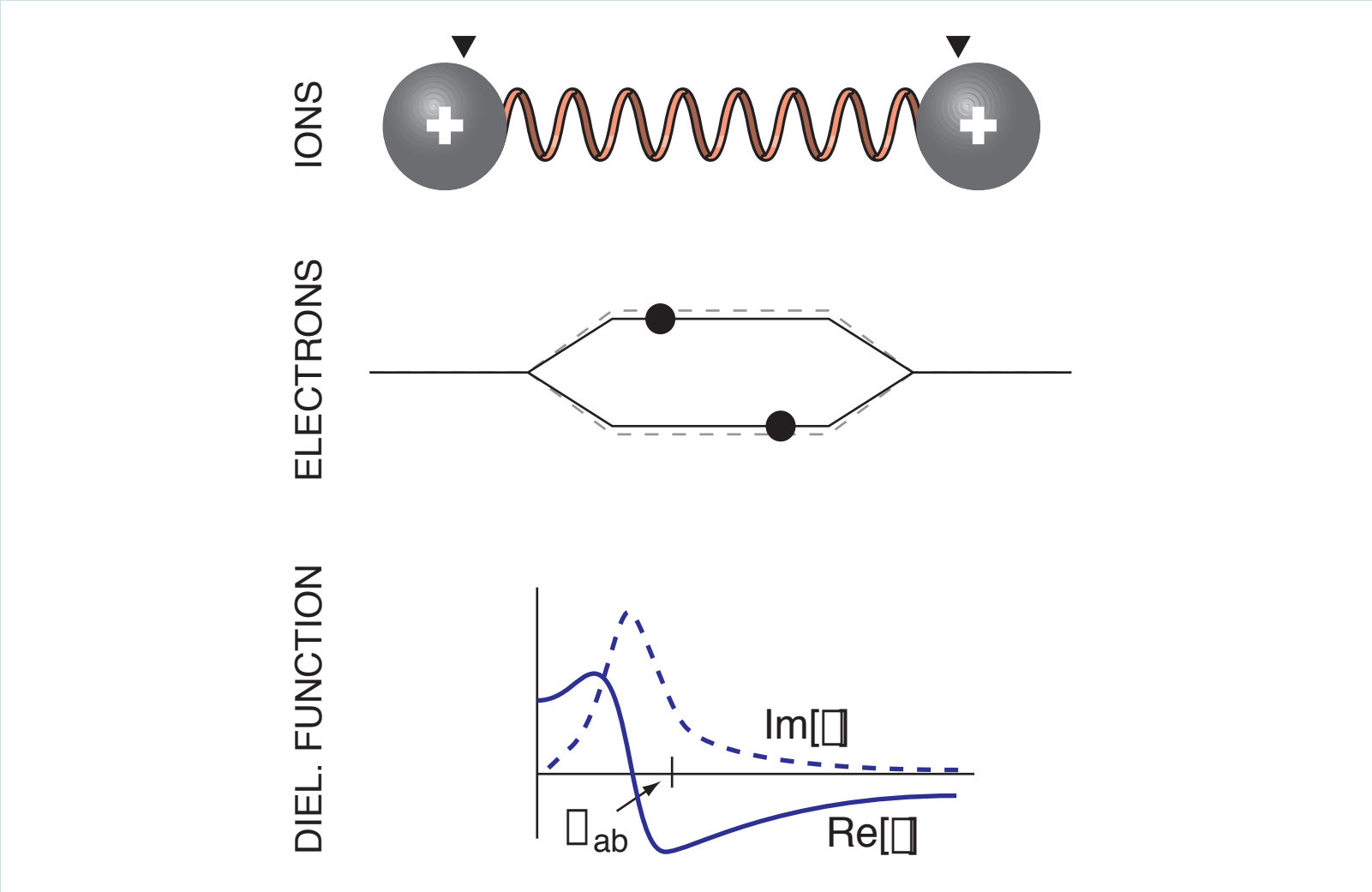
... decreasing the splitting...

"Two-atom" model



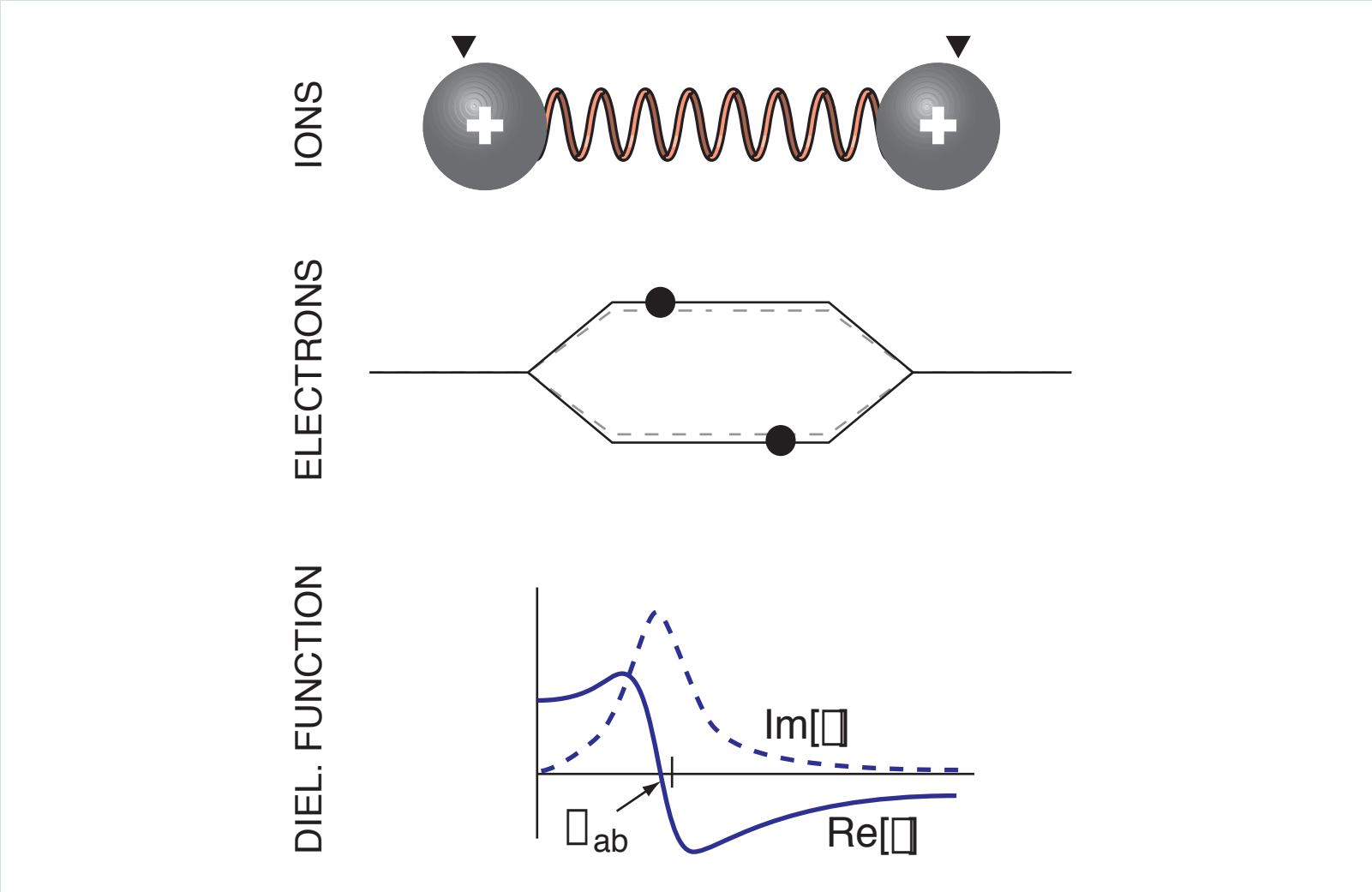
... and redshifting the dielectric function

"Two-atom" model



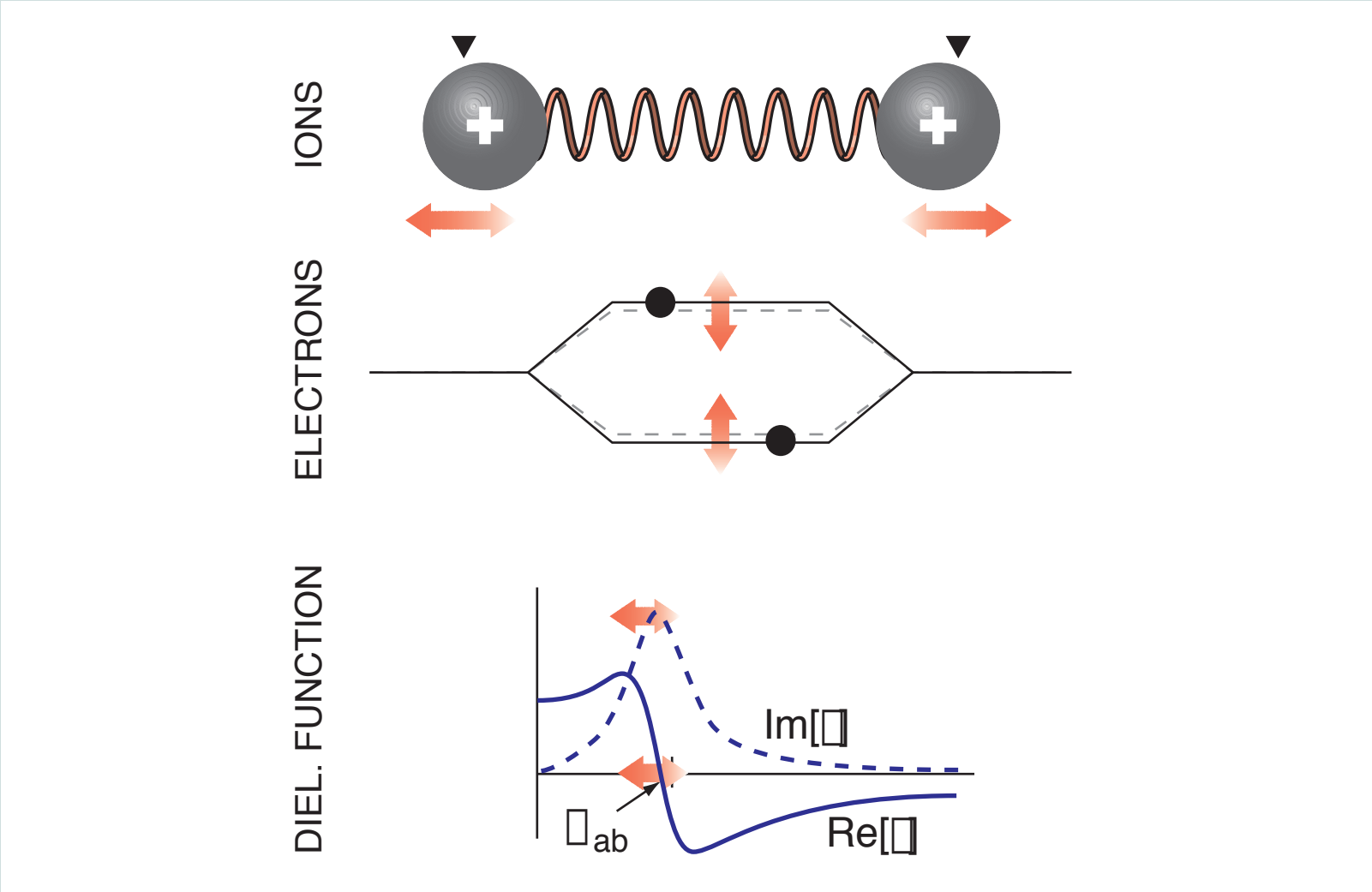
ions overshoot equilibrium positions...

"Two-atom" model



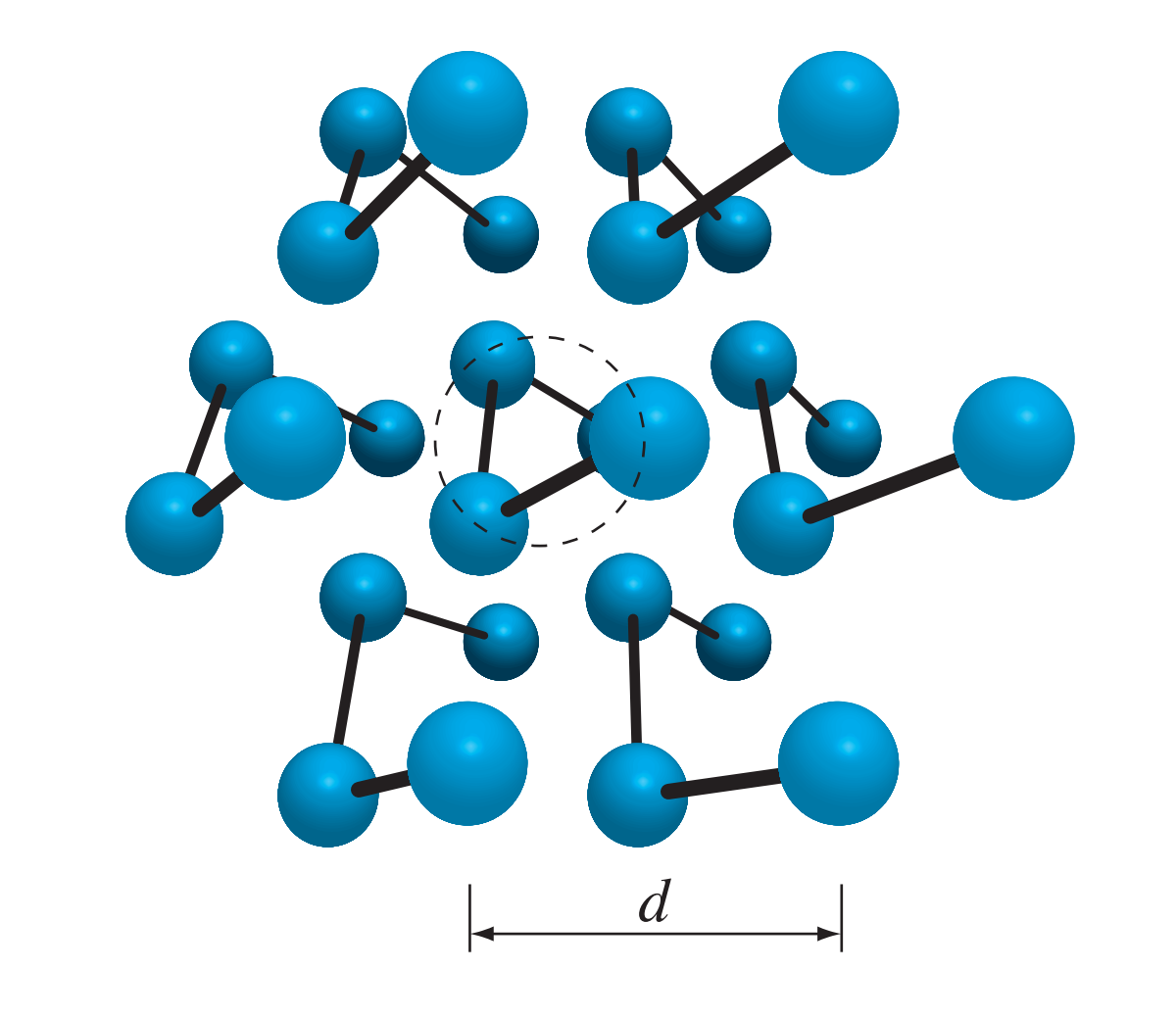
... reversing travel and overshooting again

"Two-atom" model



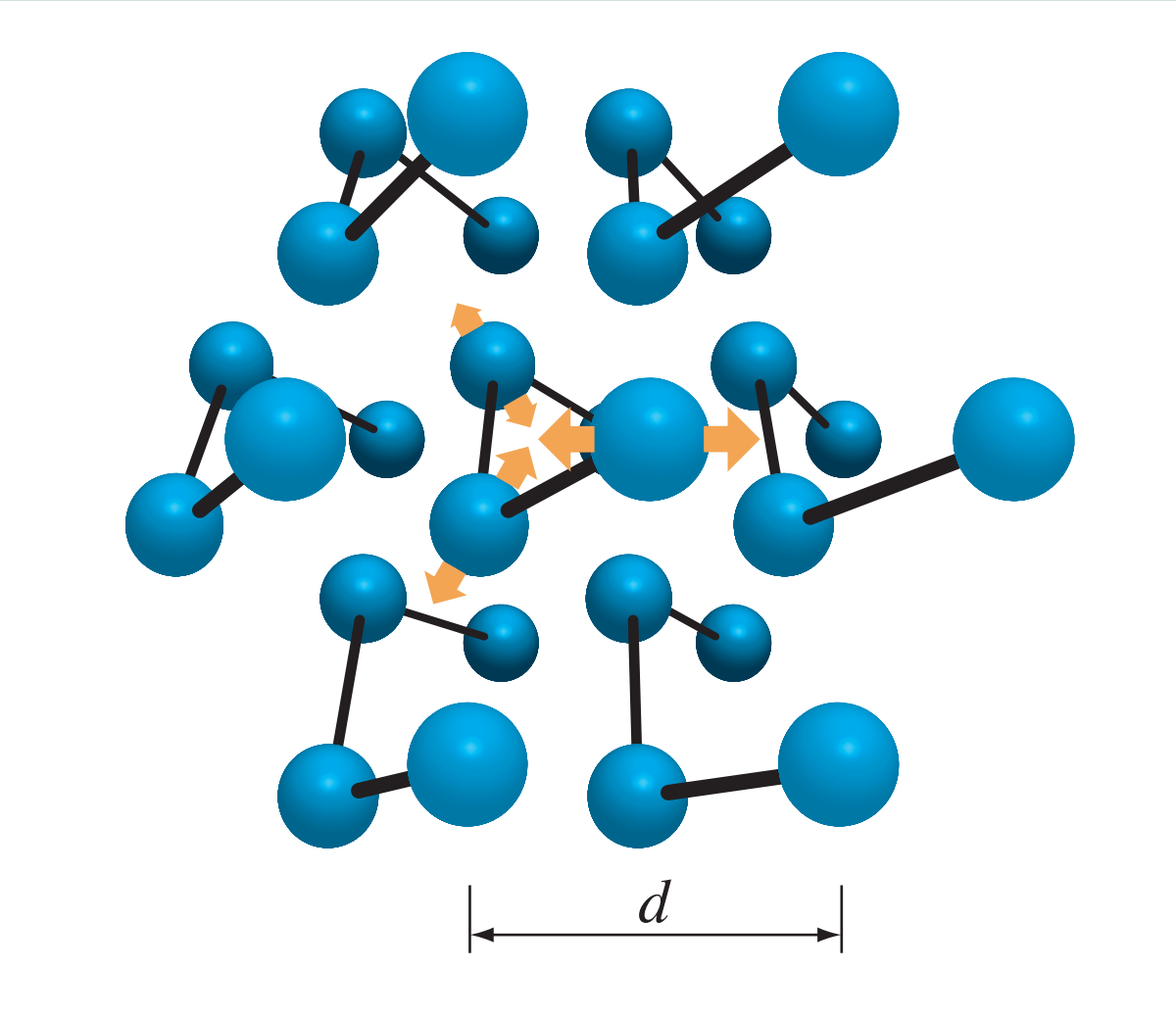
oscillation around displaced equilibrium position

Tellurium lattice



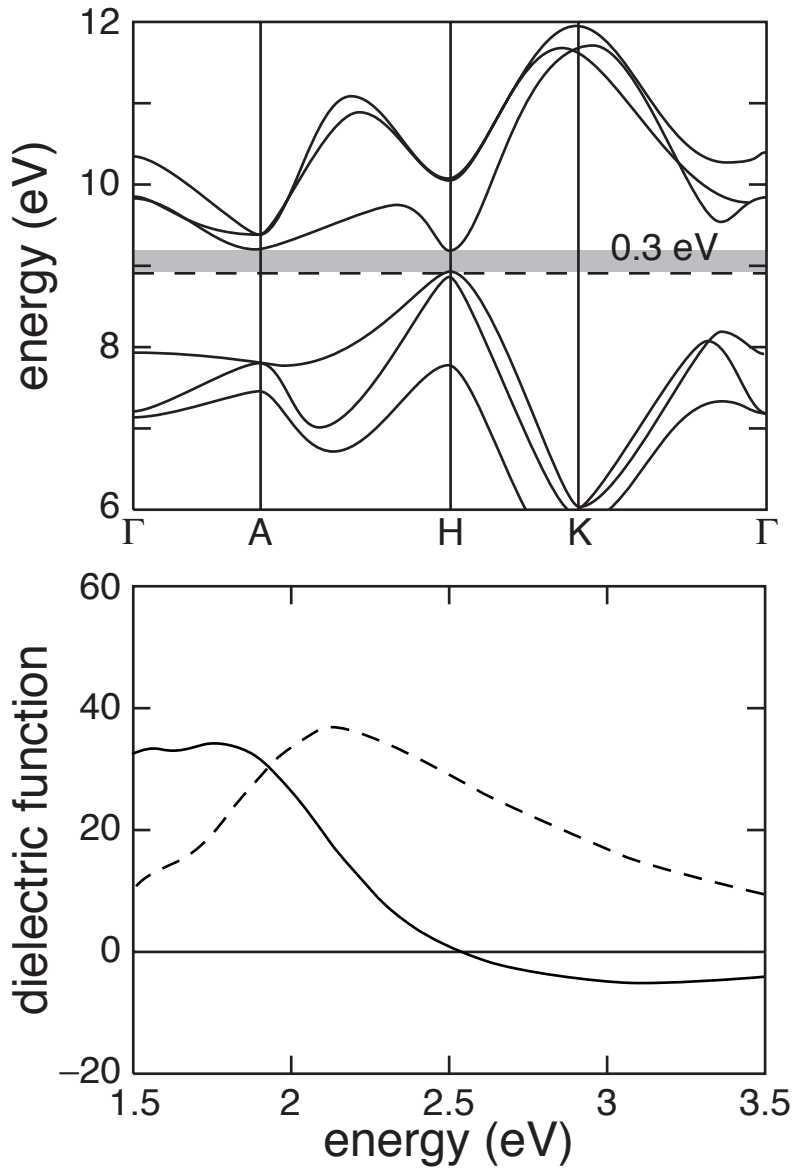
helical radius x=0.26d

Tellurium lattice



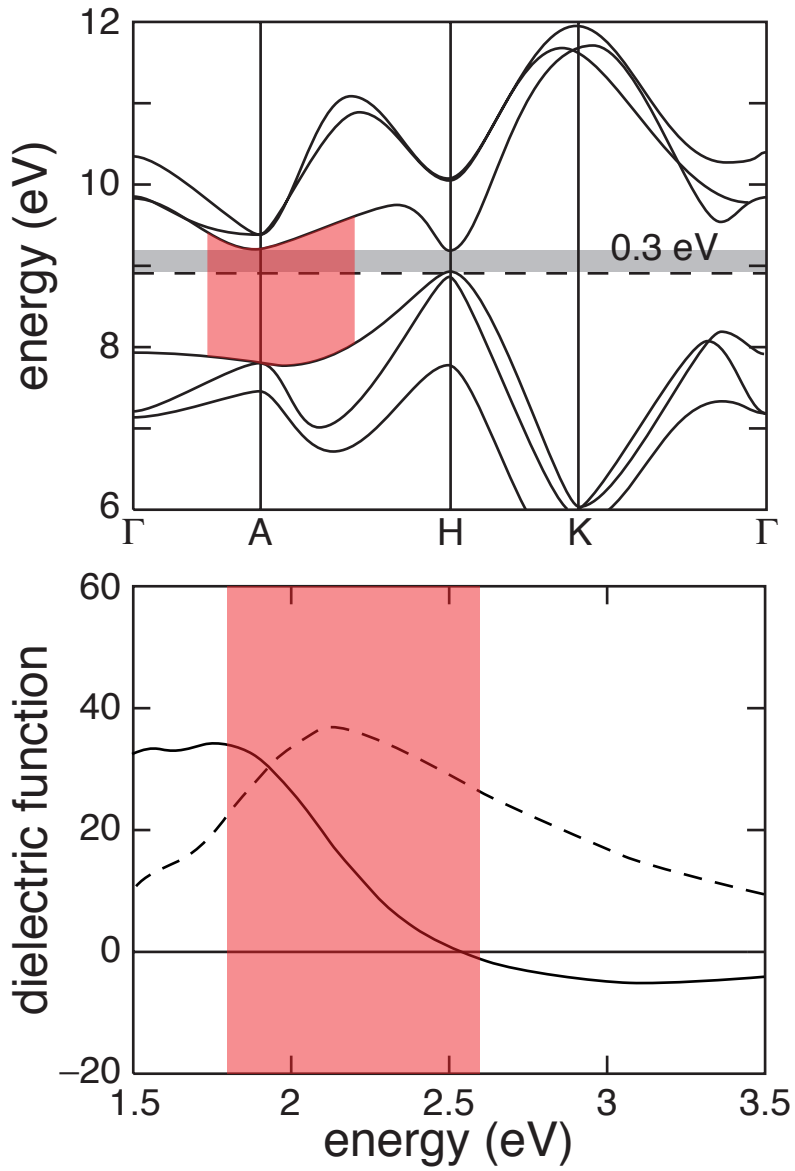
A_1 mode modulates helical radius

Properties at equilibrium displacement



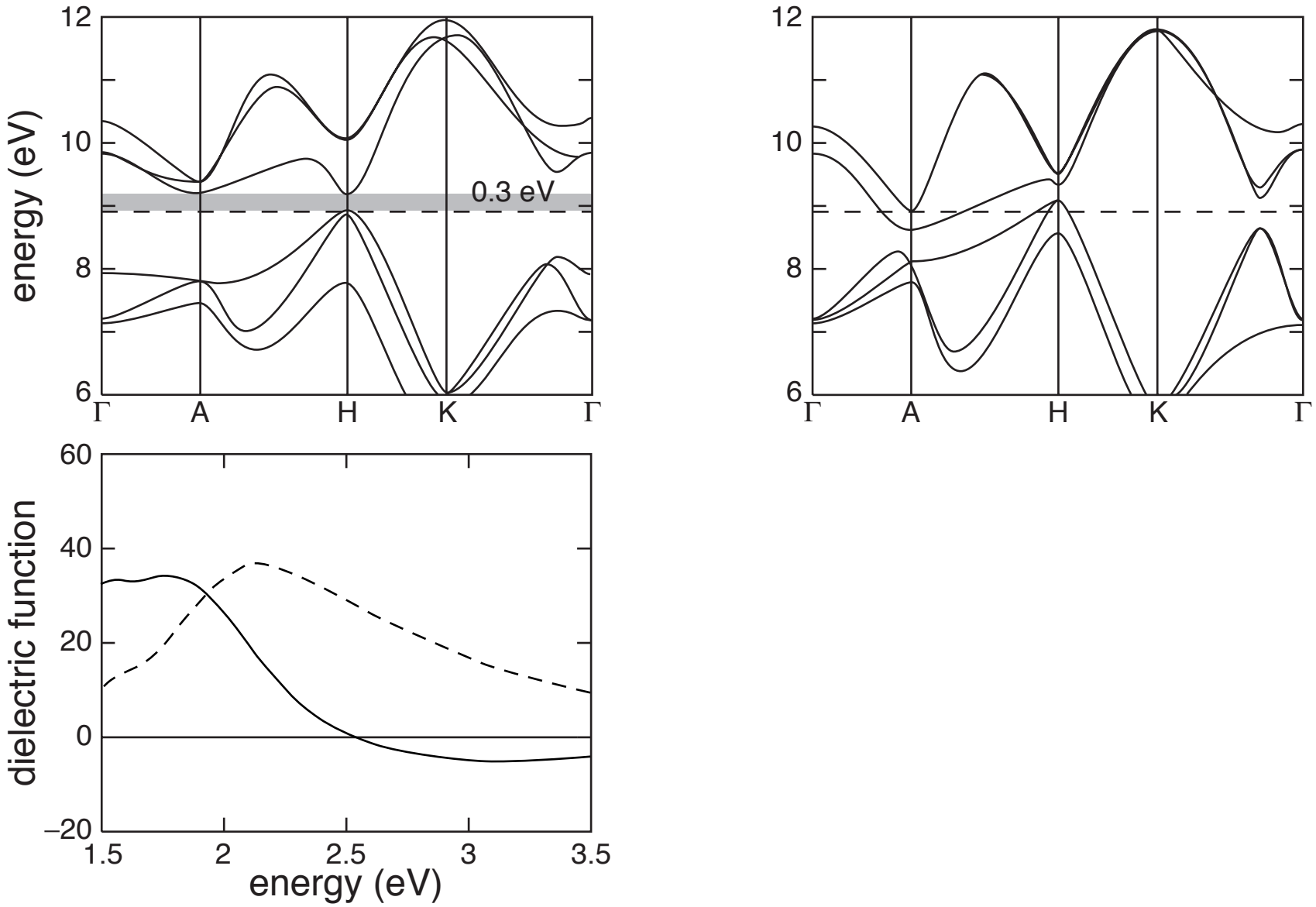
DFT calculations by
P. Tangney (Princeton) and
S. Fahy (Cork)

Properties at equilibrium displacement

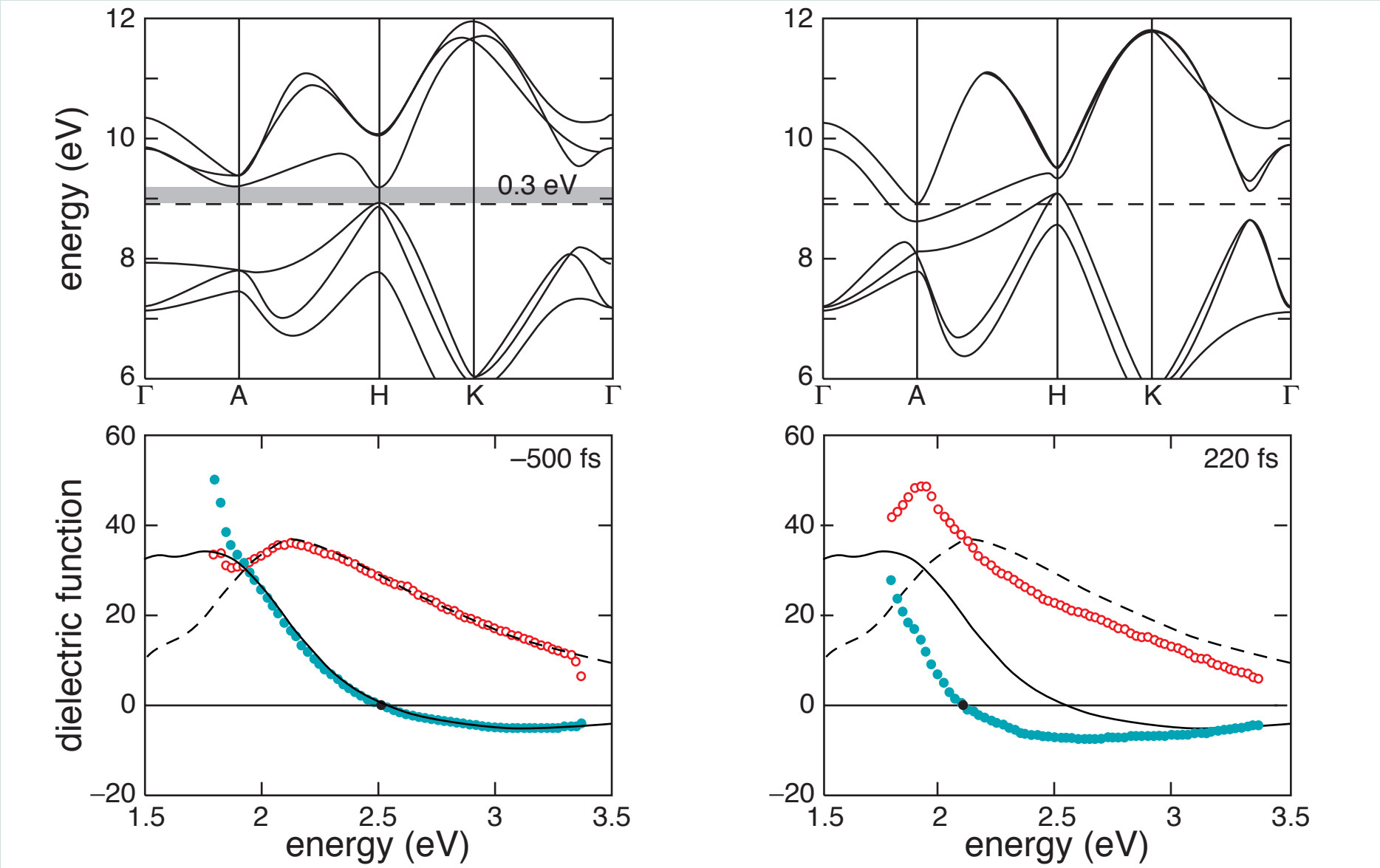


Transitions at A produce main resonance near 2.2 eV

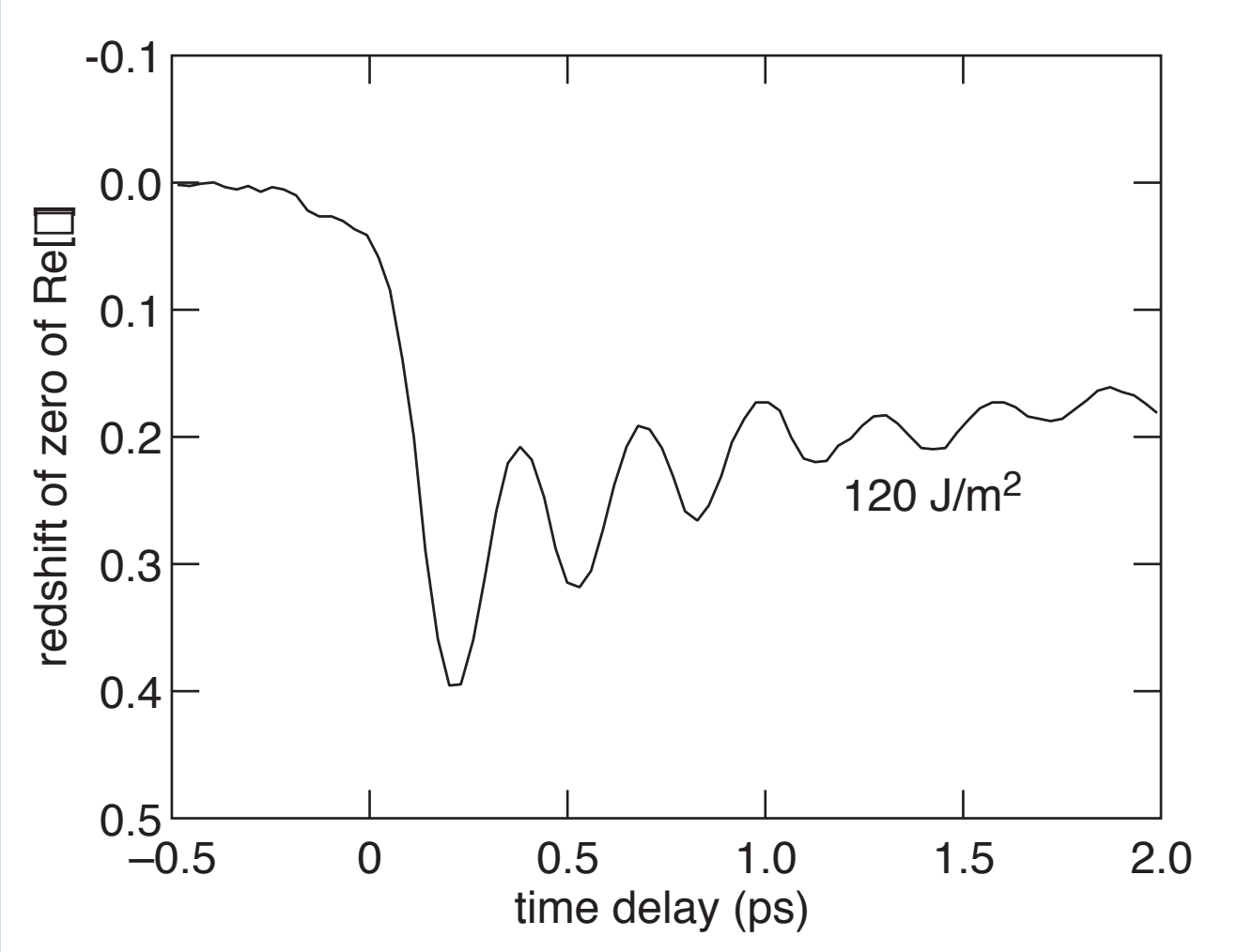
Lattice displacement redshifts resonance



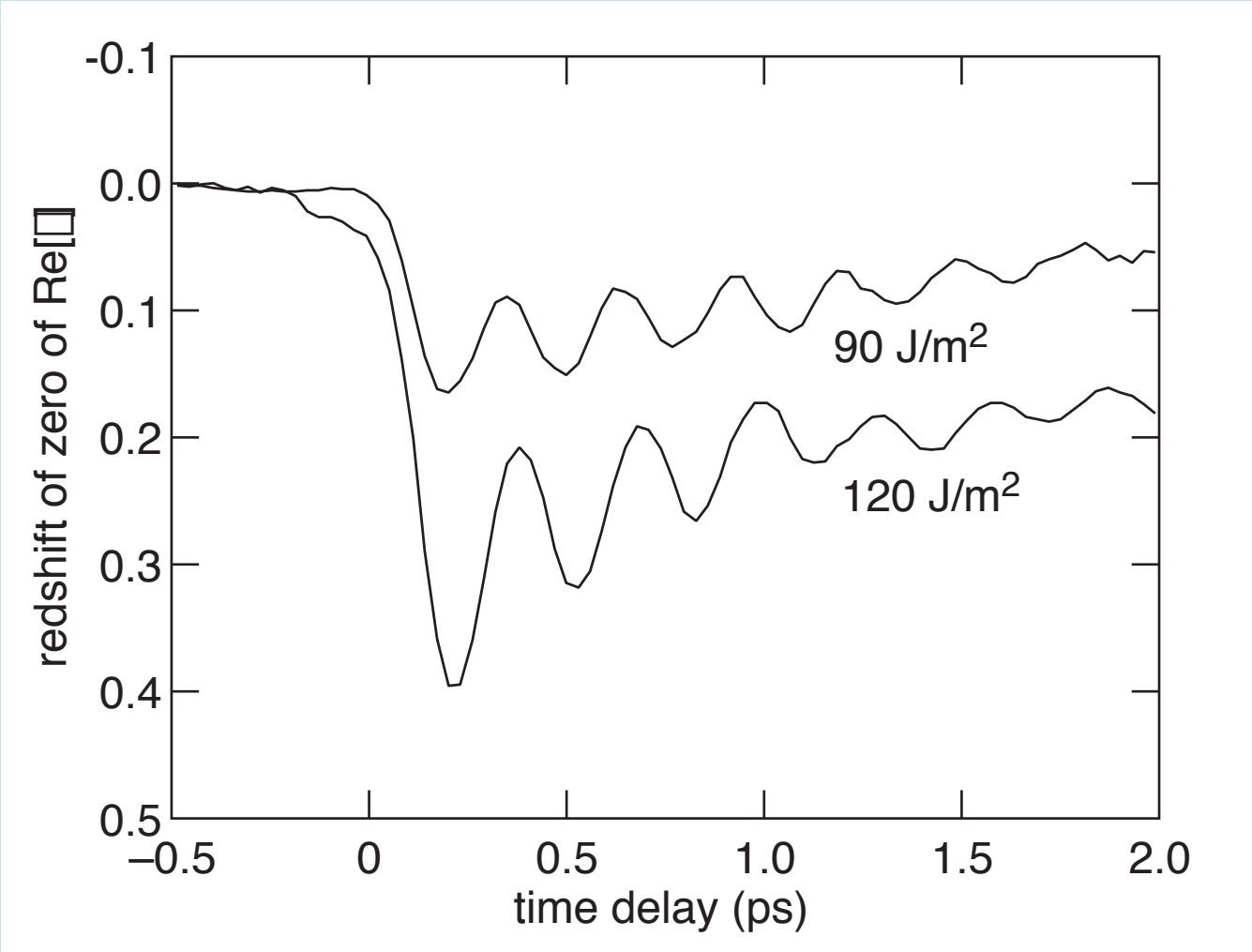
Track changes with ε(ω)



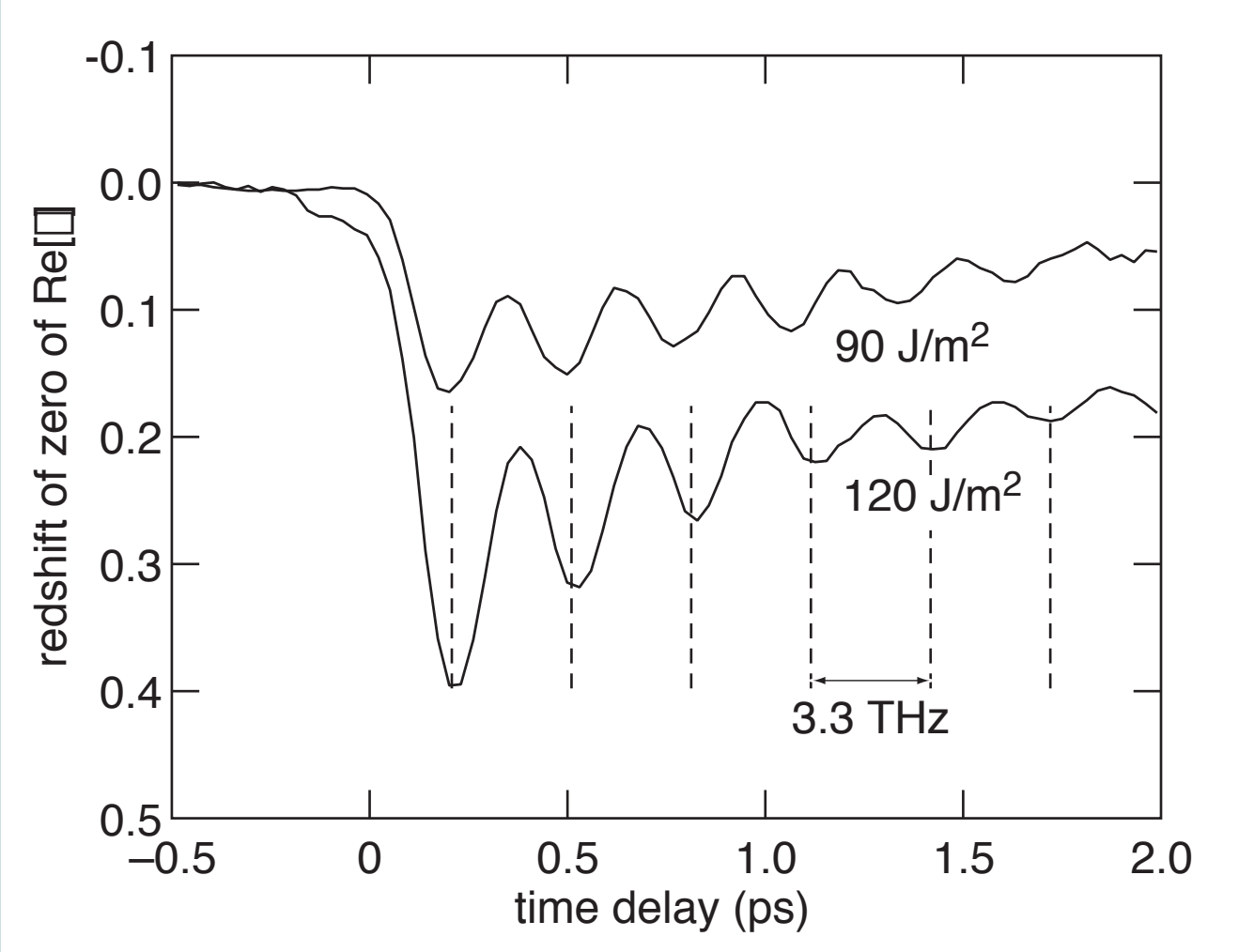
Track zero of real part



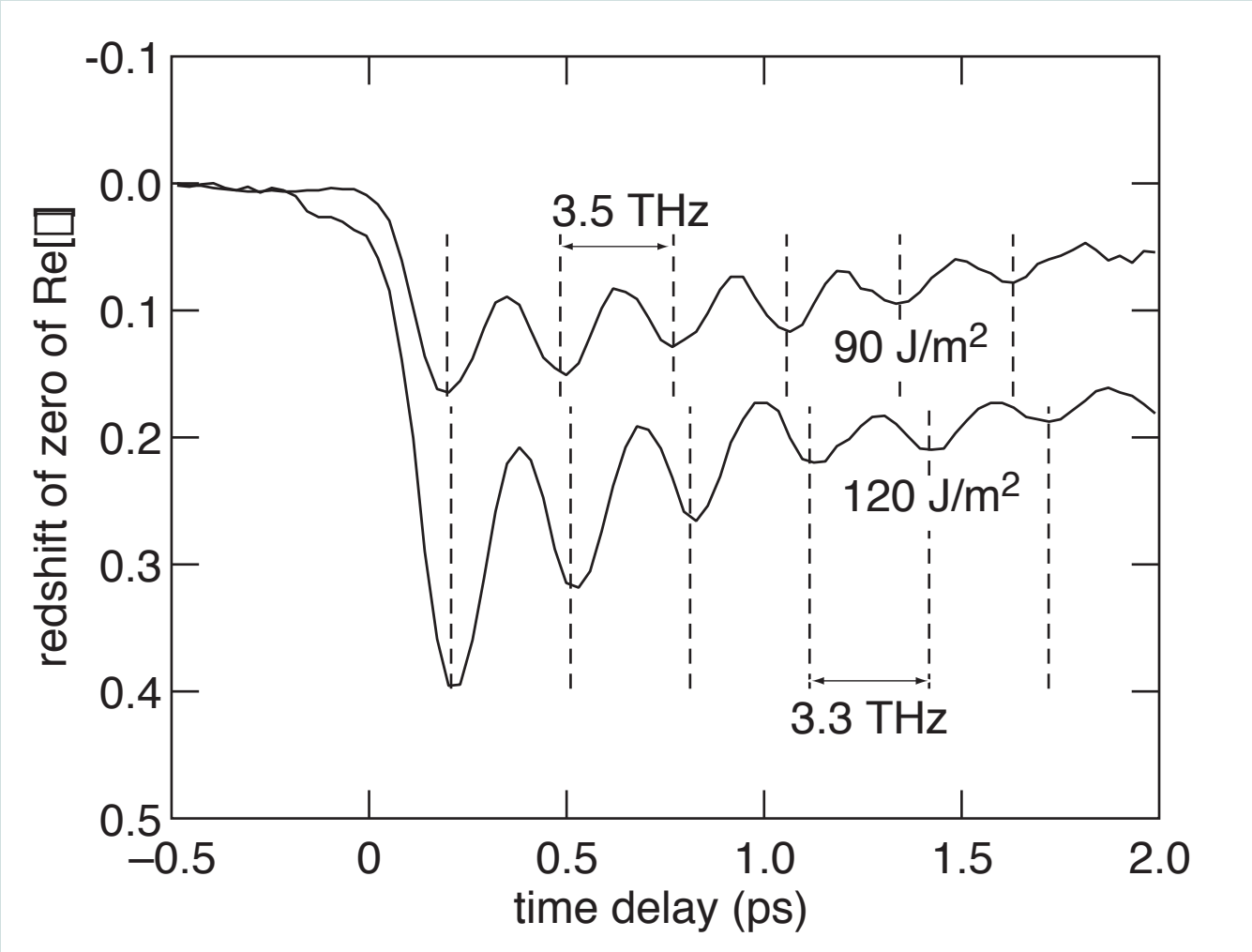
Higher fluence: larger amplitude phonons



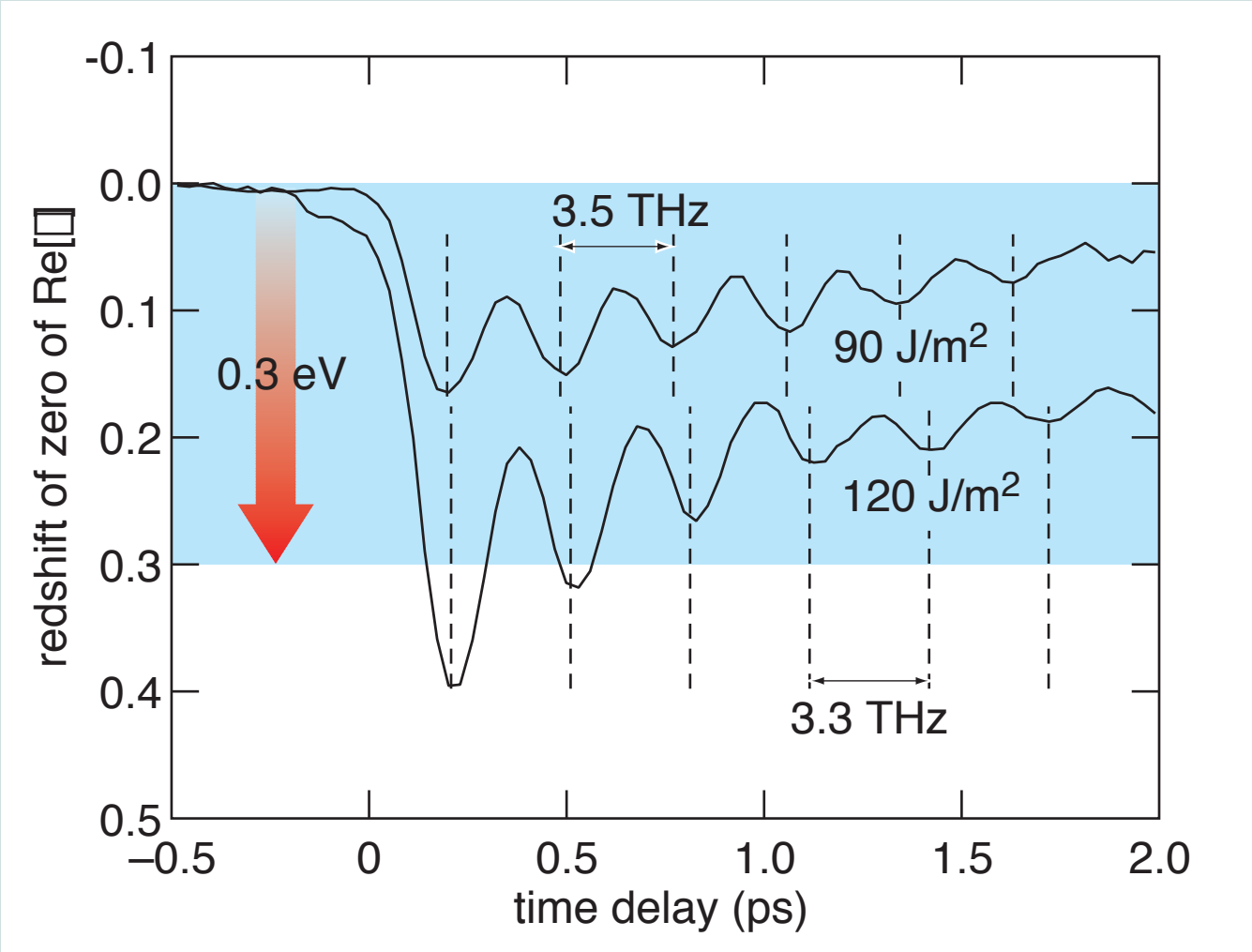
Frequency less than 3.6 THz



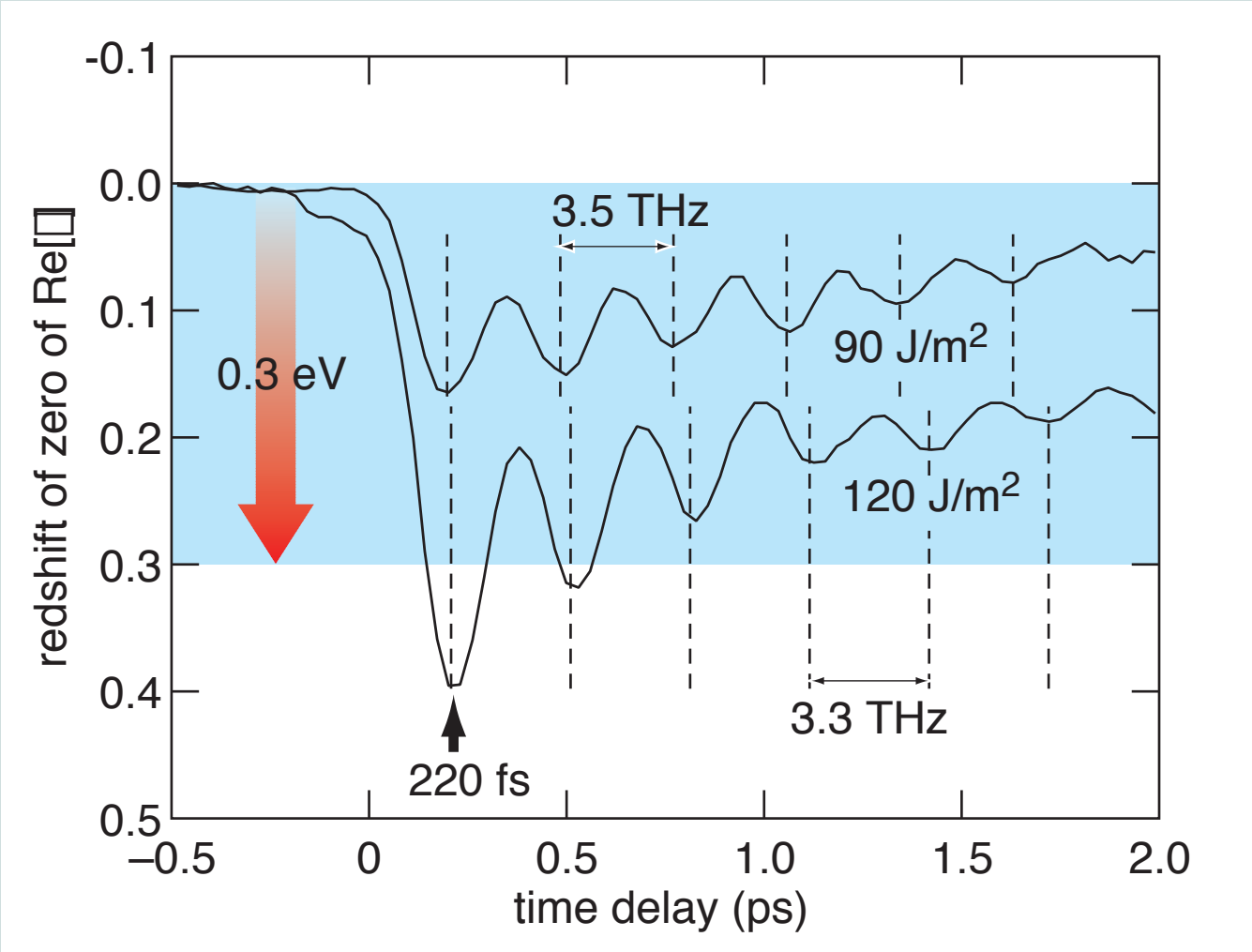
Phonon mode softens



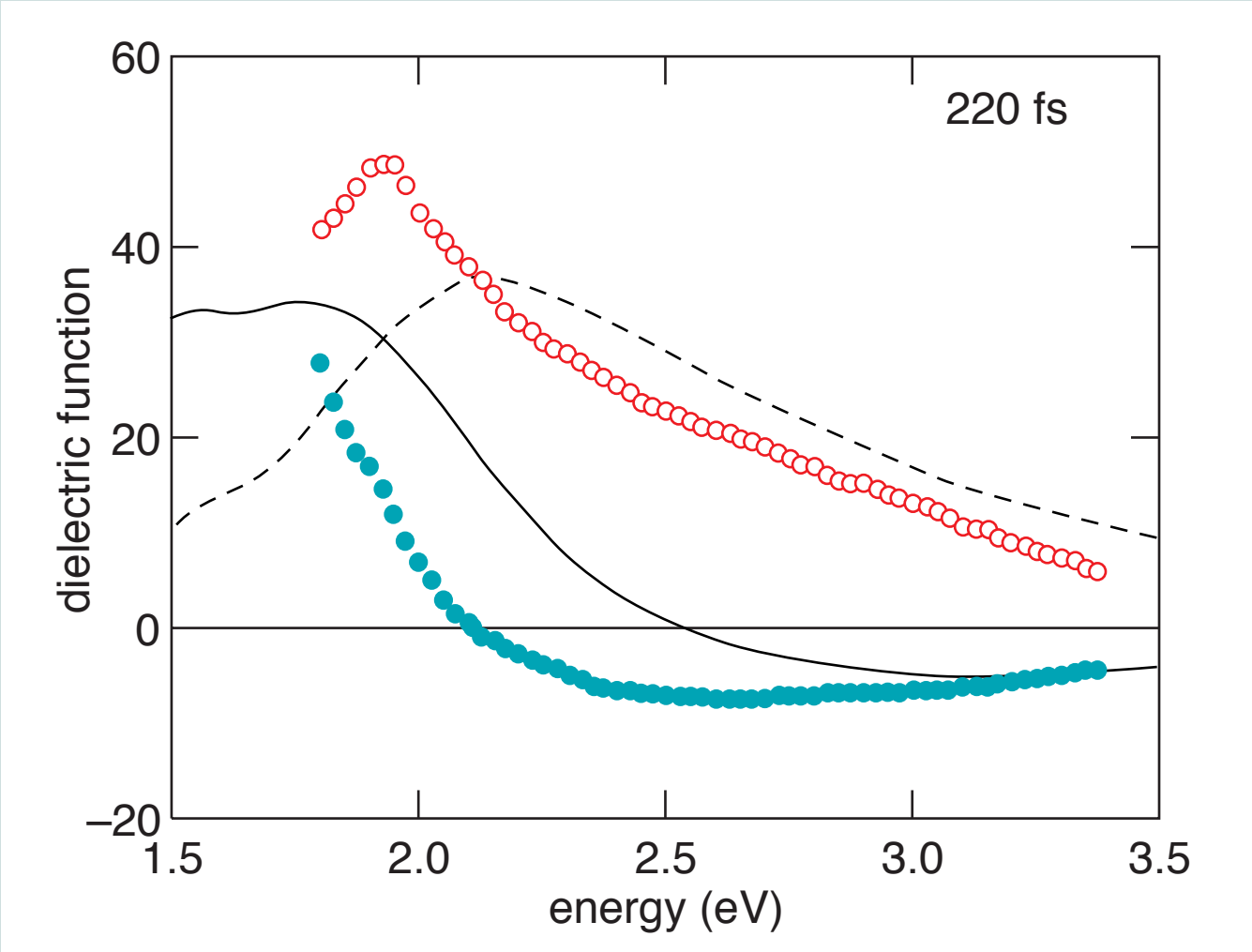
Compare shift to band gap



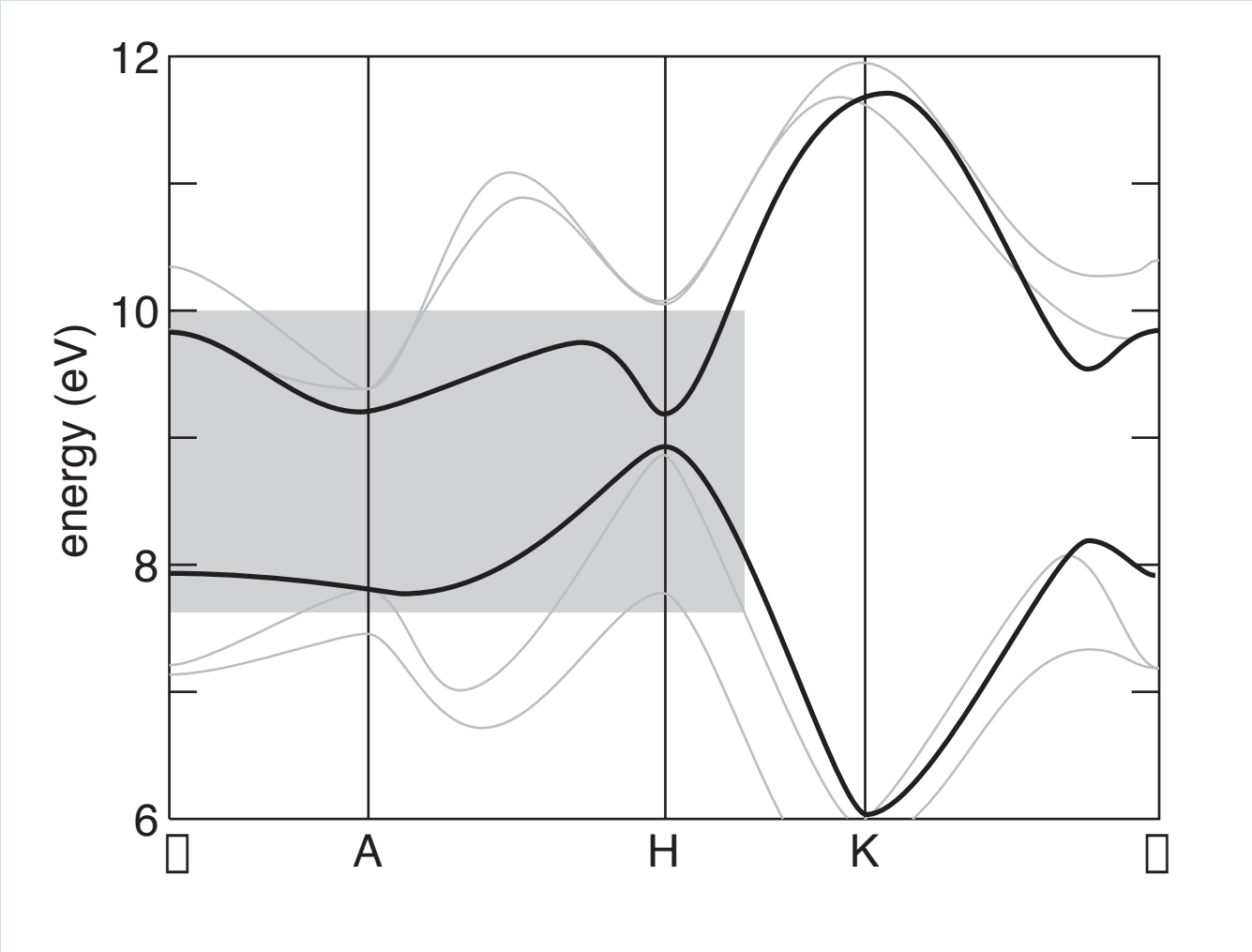
Compare shift to band gap



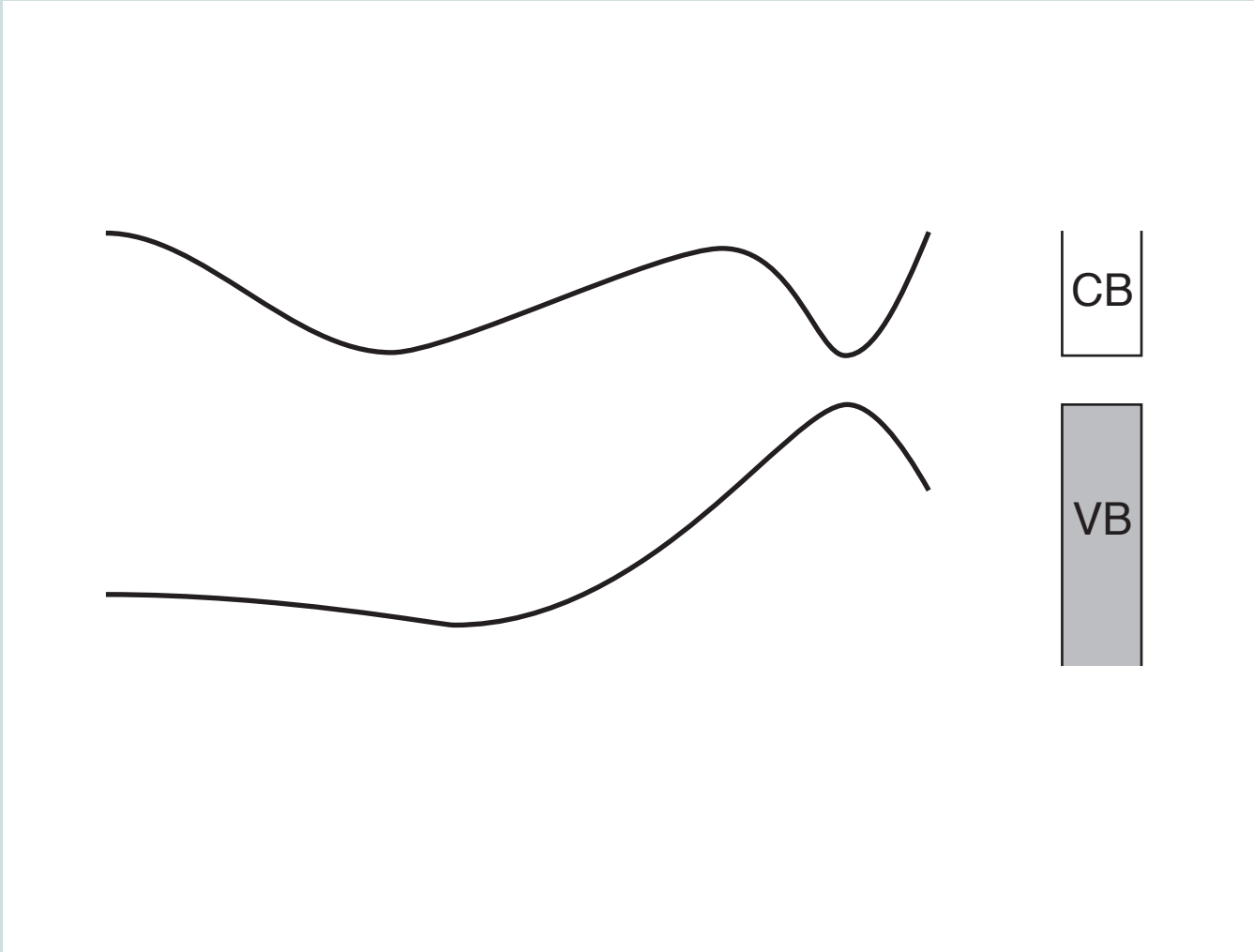
□(□) is not metallic



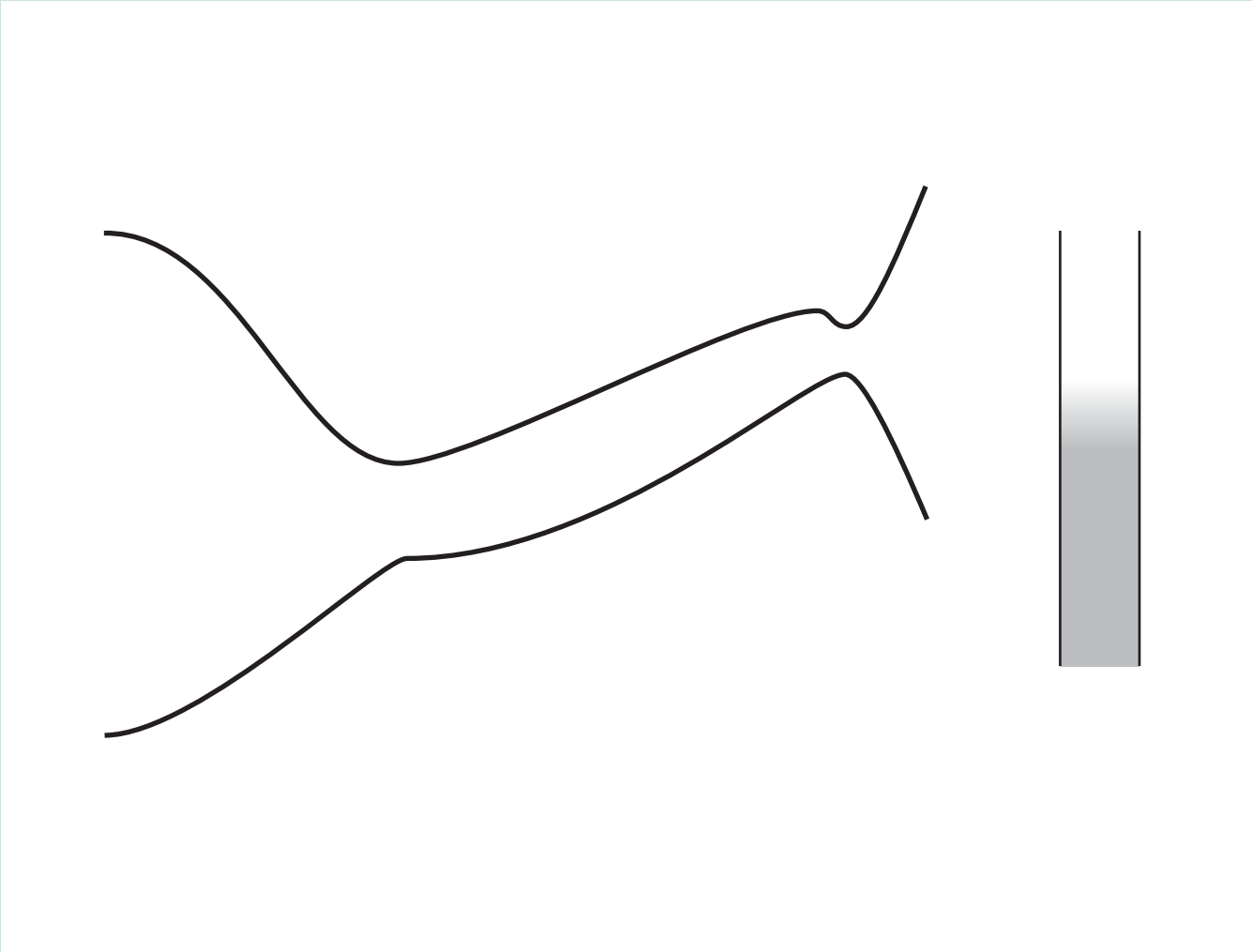
DISCUSSION



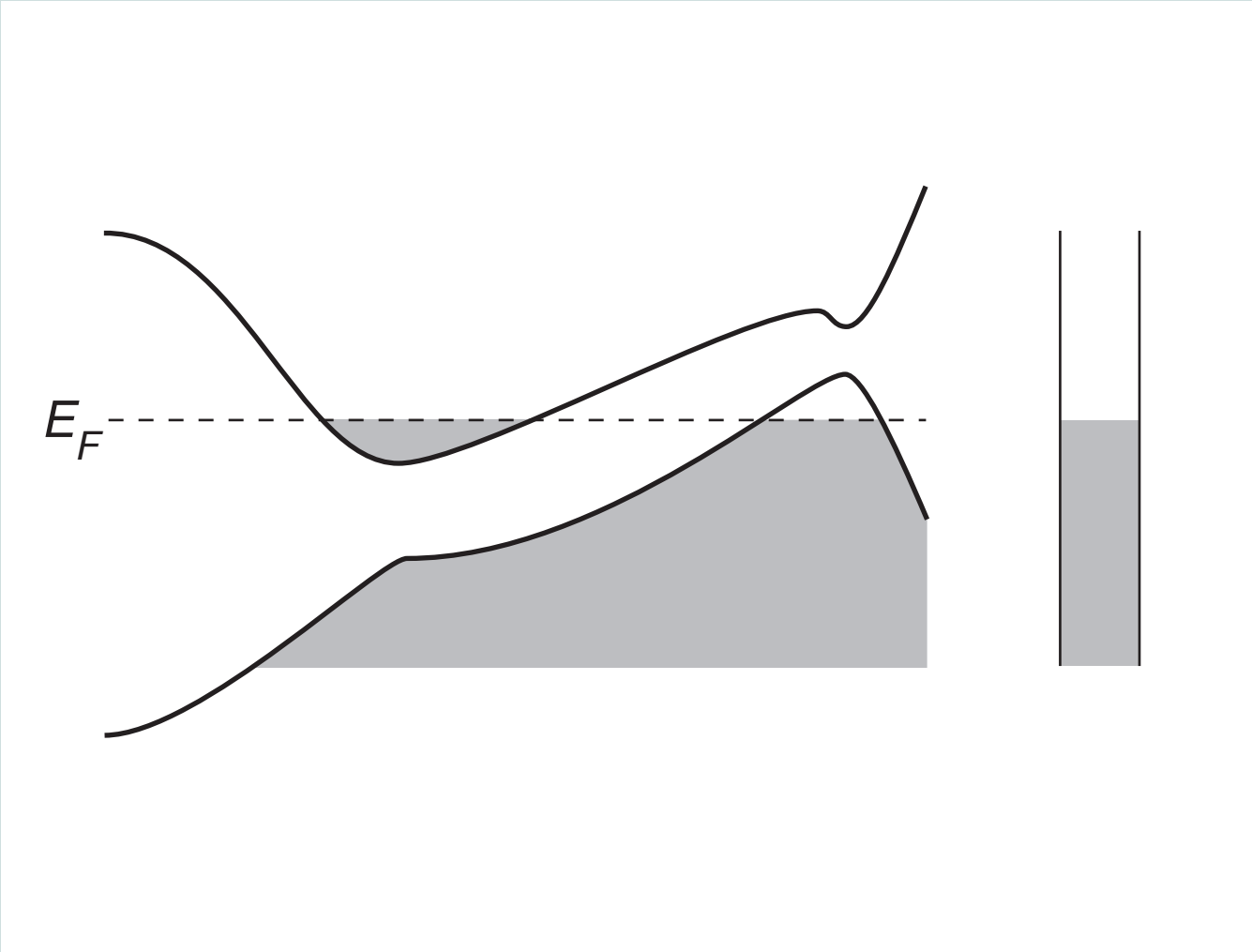
Semiconducting because of 0.3-eV gap



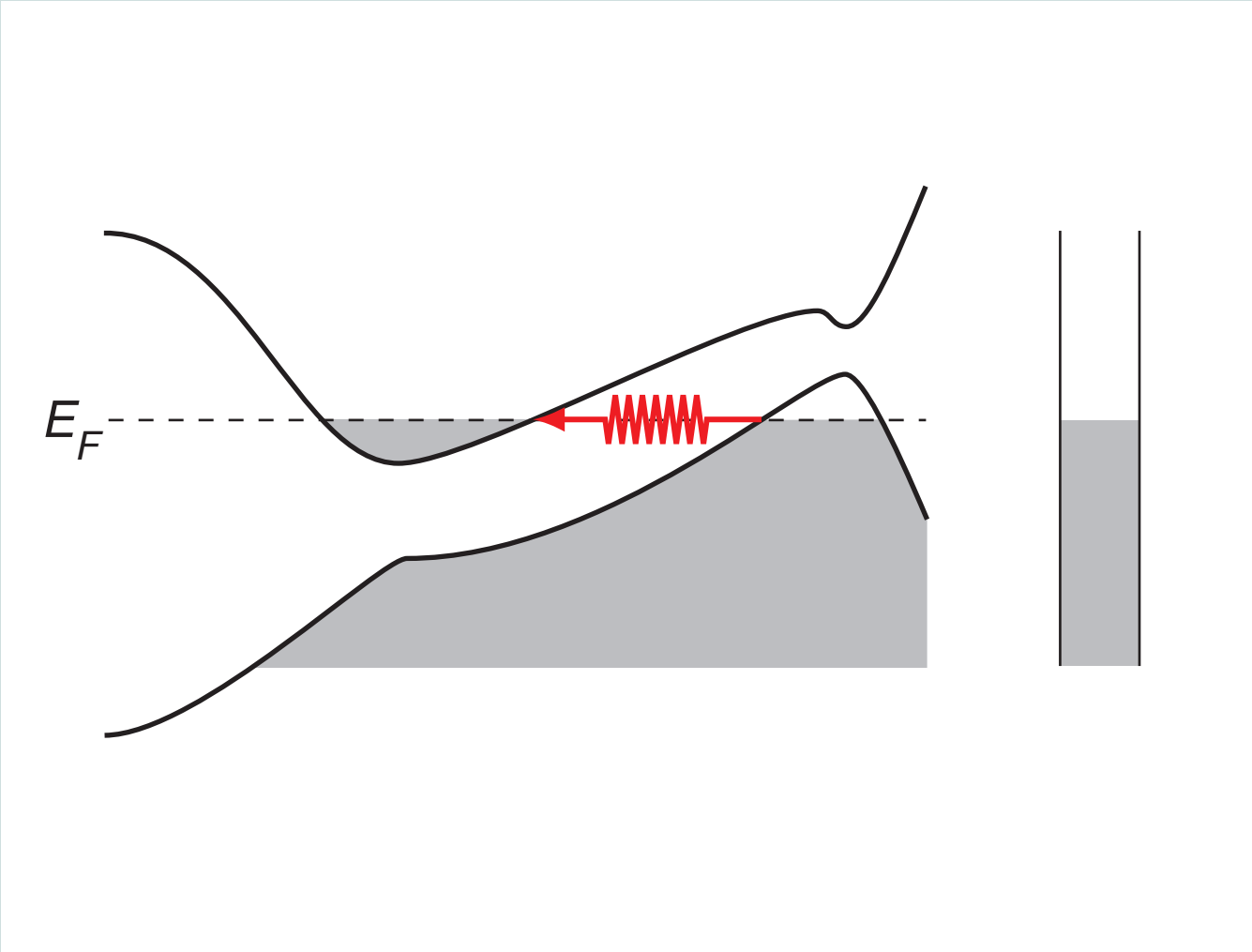
After bands cross...



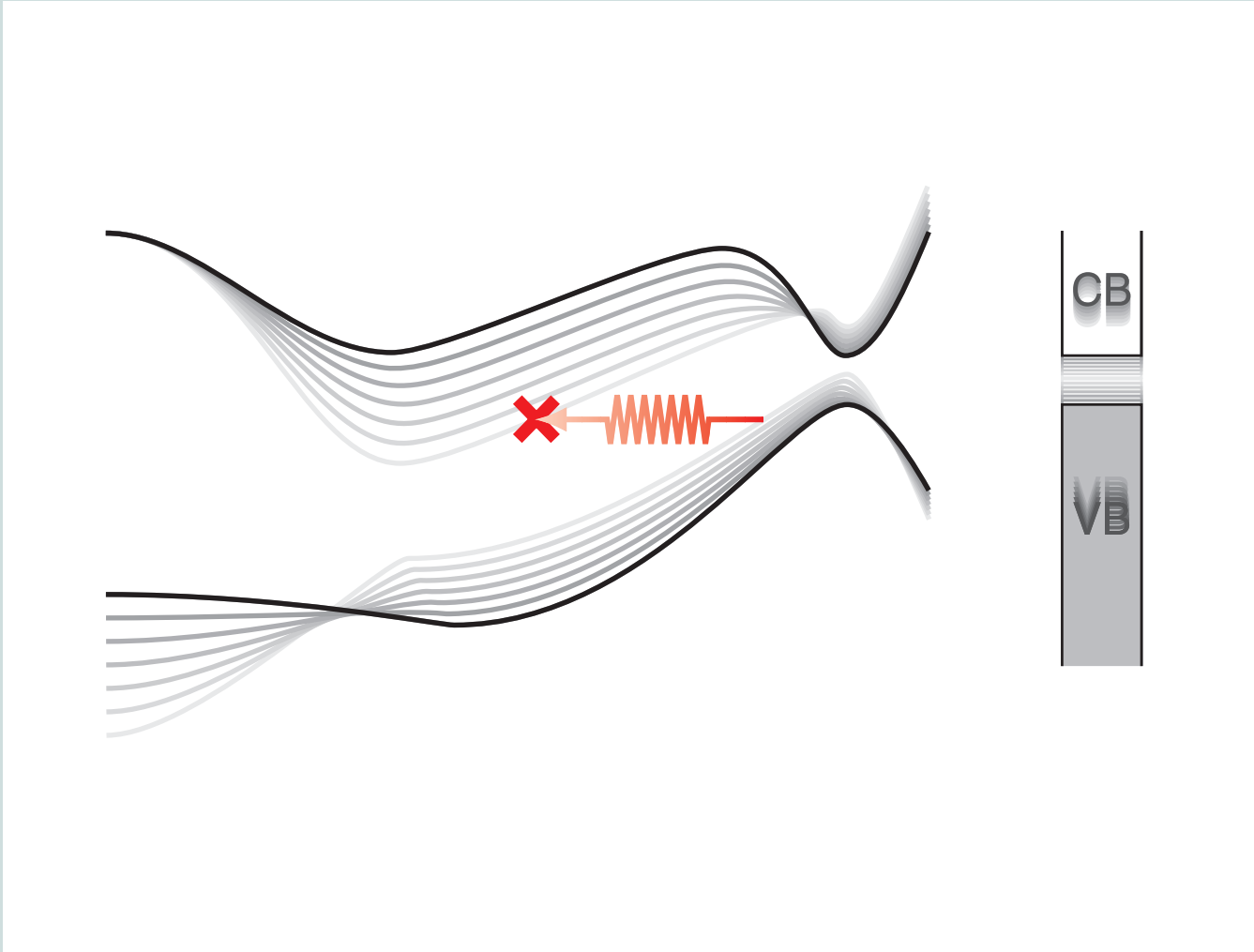
... material can become metallic...



... provided phonons scatter electrons



If $\tau_{scatter} > T_{phonon}$, 'frustrated' metal



SUMMARY

Measuring dielectric tensor enables device design

Evidence for transient band-crossing in tellurium

... but metal may be frustrated

Funding: National Science Foundation

Acknowledgments:

Dr. Peter Grosse (Aachen)
Dr. Paul Tangney (Princeton)
Prof. Steven Fahy (Cork)
Nick Choly (Harvard University)
Prof. Tim Kaxiras (Harvard University)

For a copy of this talk and additional information, see:

http://mazur-www.harvard.edu