



FROM SEMICONDUCTOR TO METAL IN A FLASH

femtosecond electron and lattice dynamics

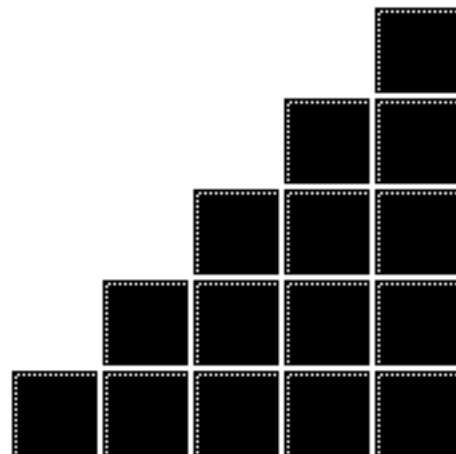
Eli Glezer

Li Huang

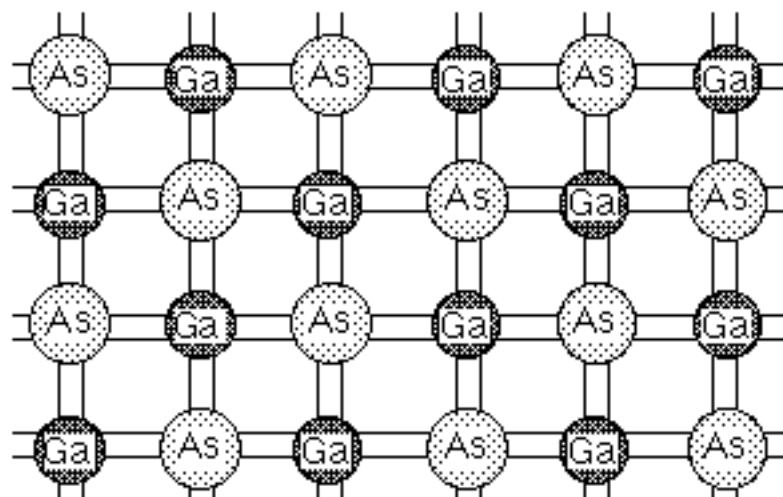
Paul Callan

University of Minnesota

25 February 1997



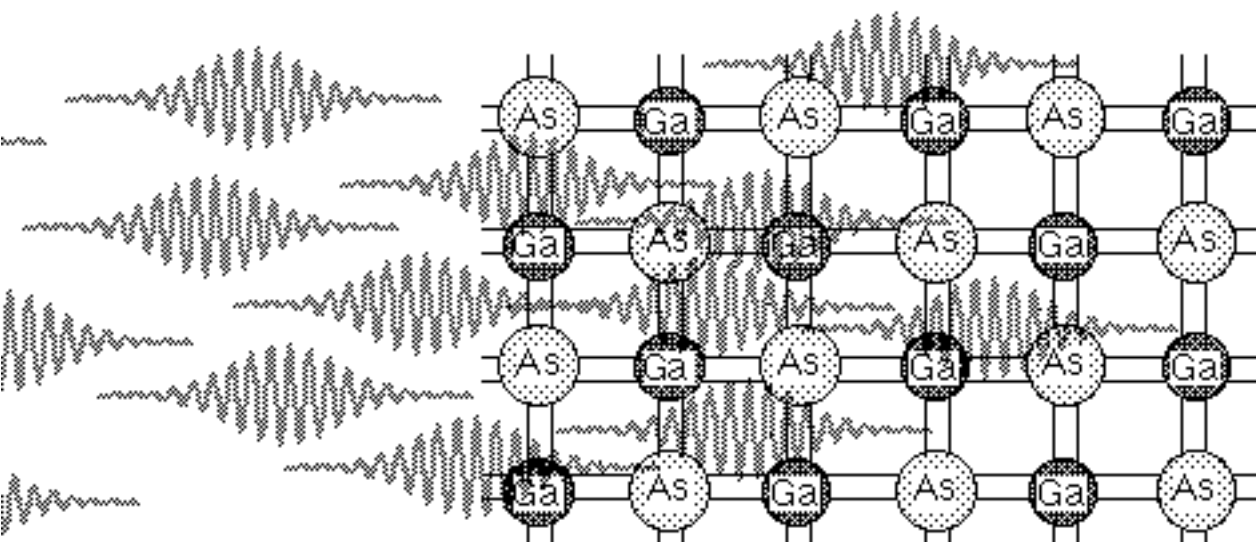
INTRODUCTION



how does light melt a solid?



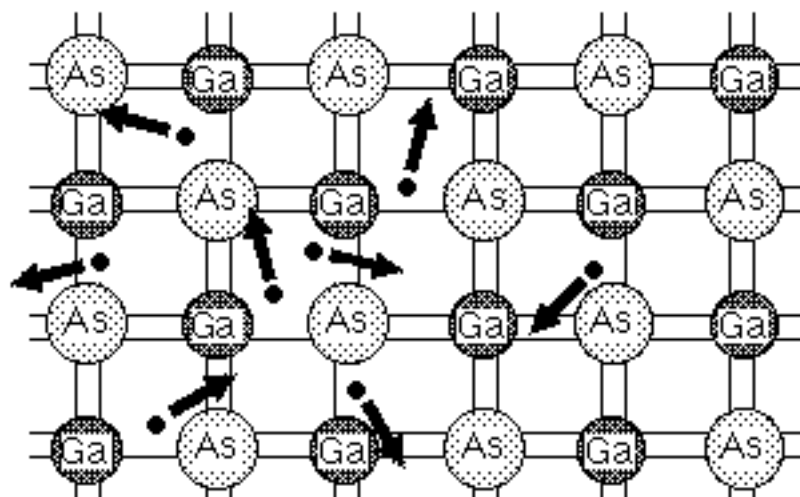
INTRODUCTION



photons excite valence electrons...



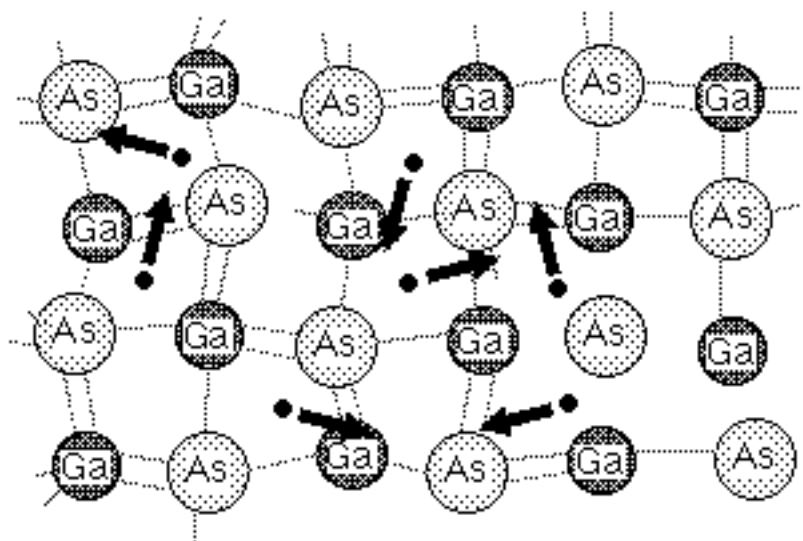
INTRODUCTION



...and create free electrons...



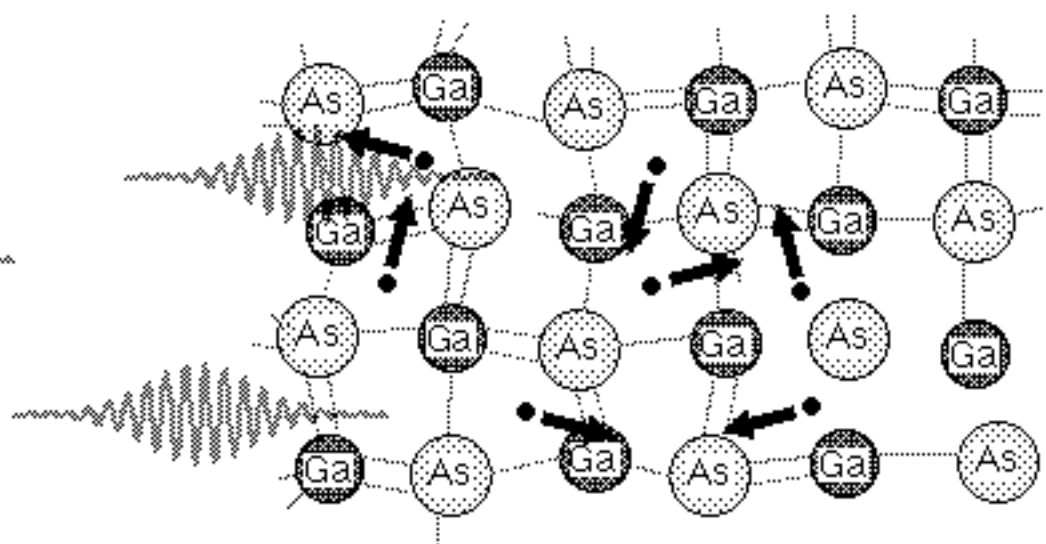
INTRODUCTION



... causing electronic & structural changes...



INTRODUCTION

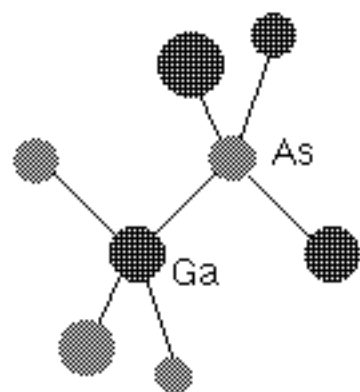


... which we measure with another pulse...



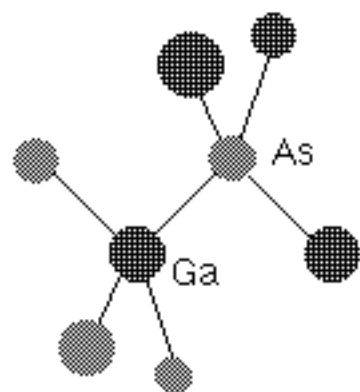
INTRODUCTION

structure



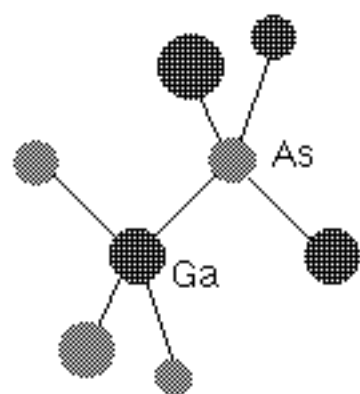
INTRODUCTION

structure

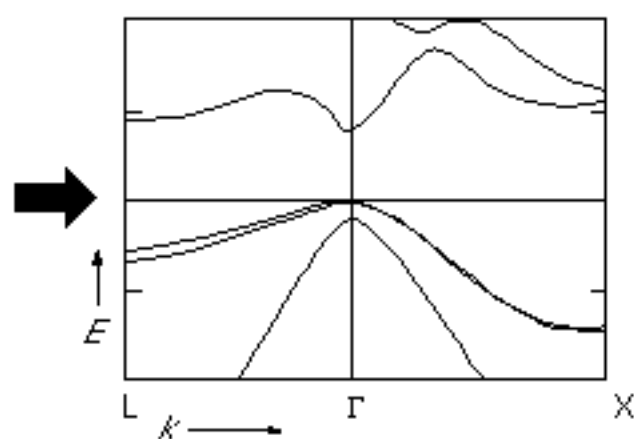


INTRODUCTION

structure

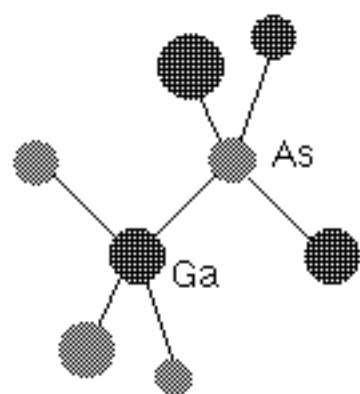


bandstructure

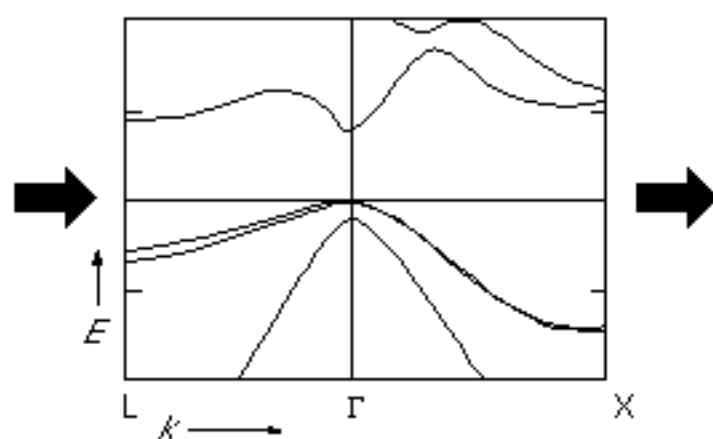


INTRODUCTION

structure

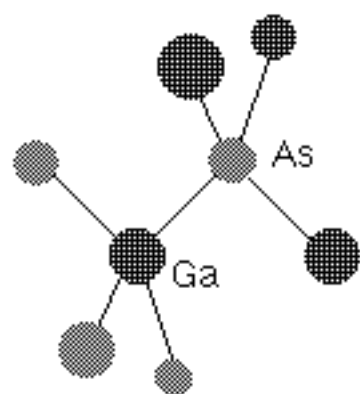


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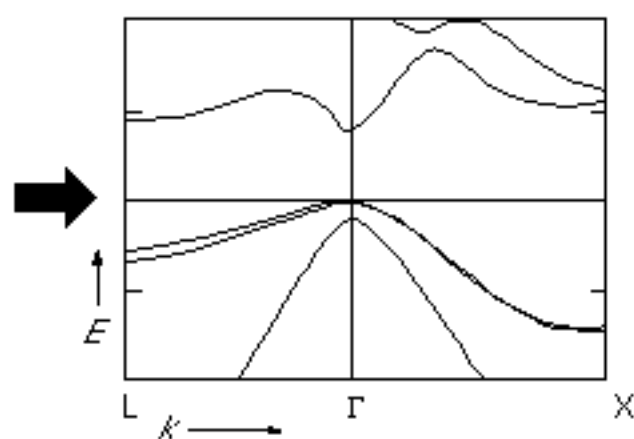


INTRODUCTION

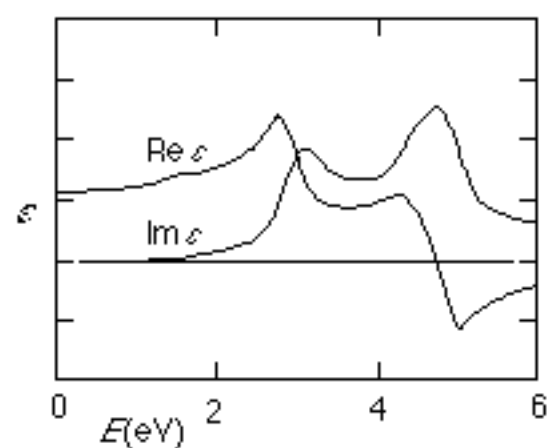
structure



bandstructure

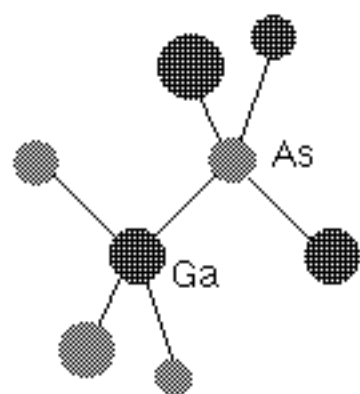


dielectric function

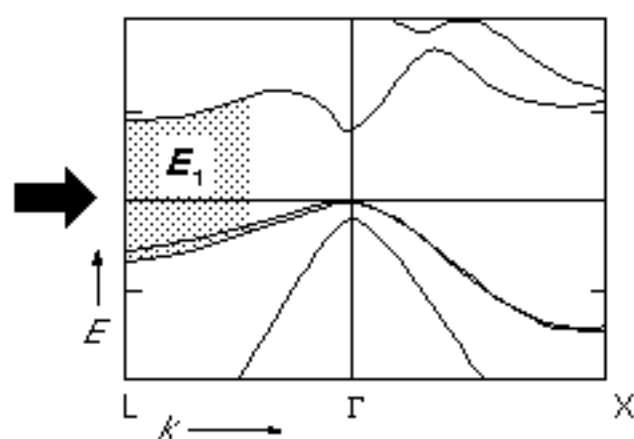


INTRODUCTION

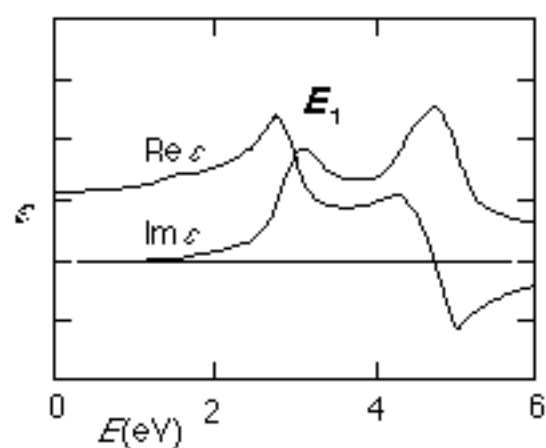
structure



bandstructure

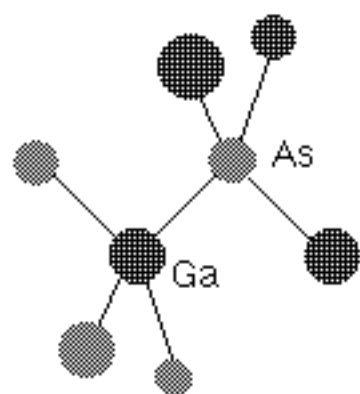


dielectric function

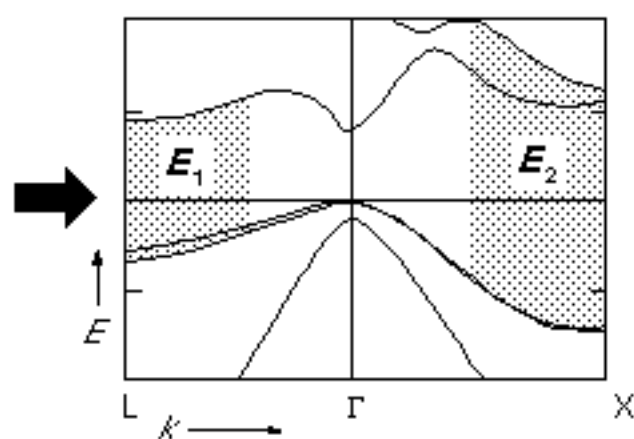


INTRODUCTION

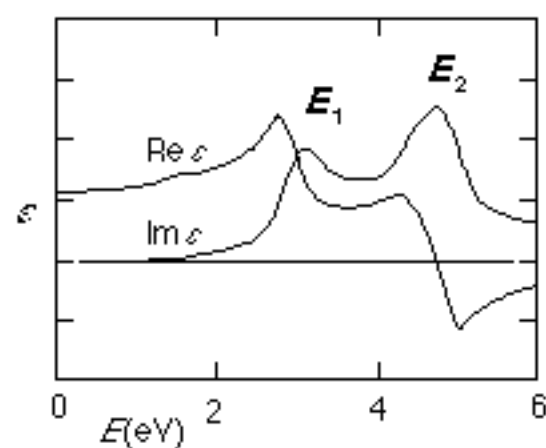
structure



bandstructure

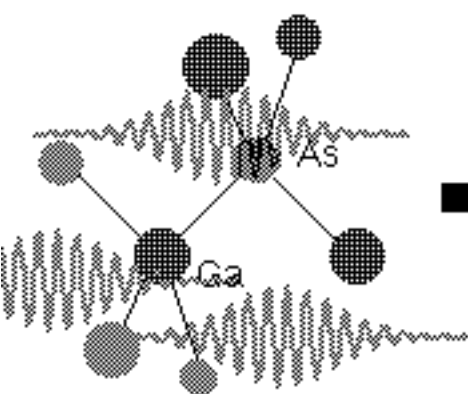


dielectric function

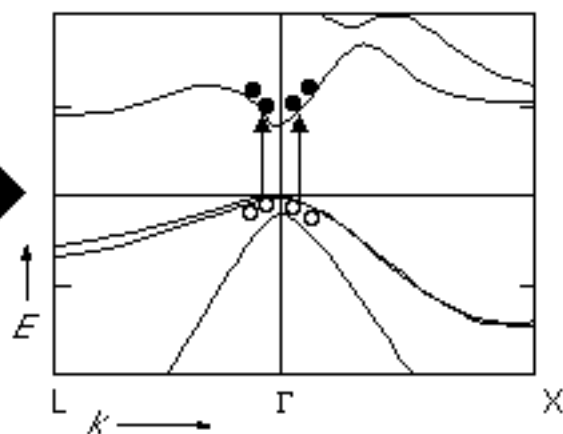


INTRODUCTION

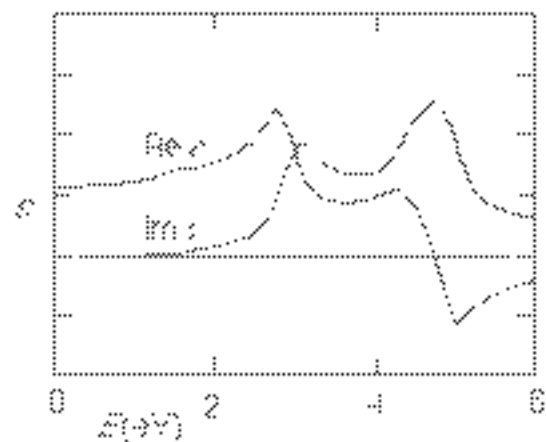
structure



bandstructure



dielectric function



70 fs, 10^{16} W/m²

10^{20} - 10^{22} cm⁻³



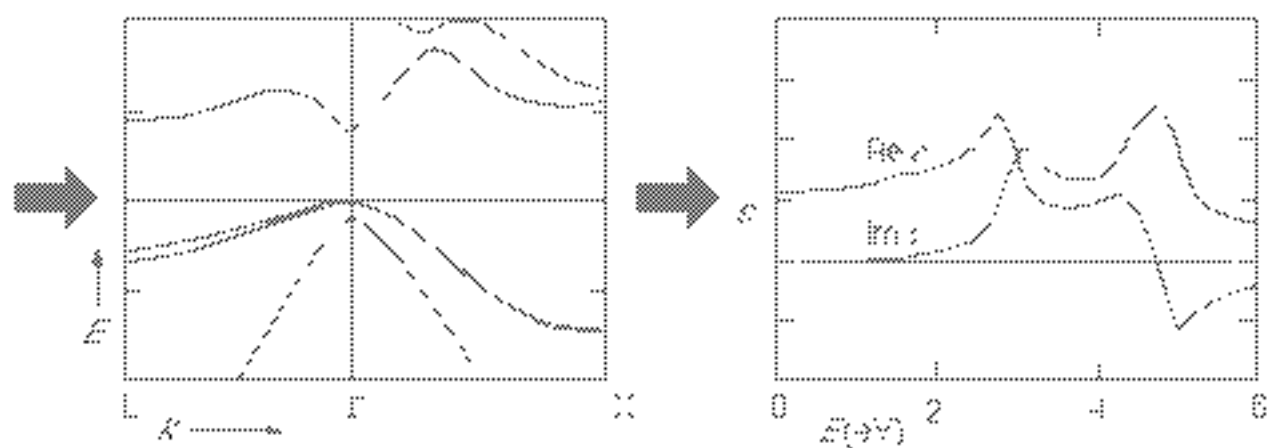
INTRODUCTION

structure

bandstructure

dielectric function

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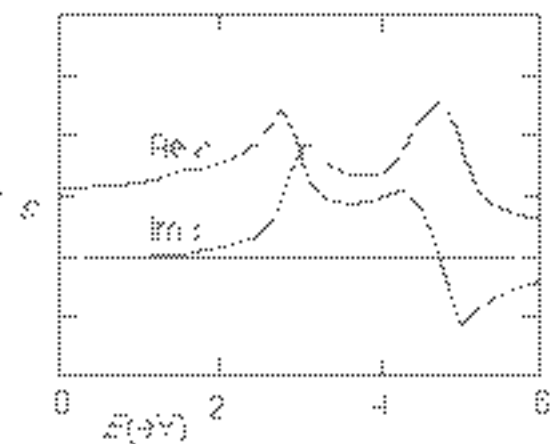
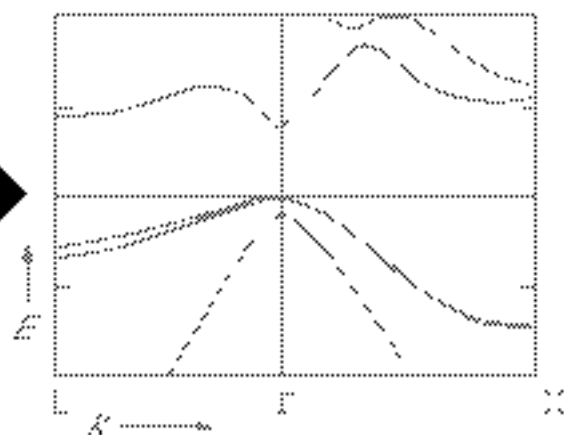
INTRODUCTION

structure

bandstructure

dielectric function

?



INTRODUCTION

structure

?

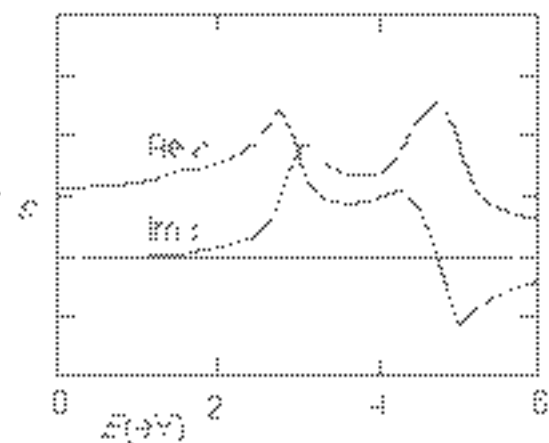
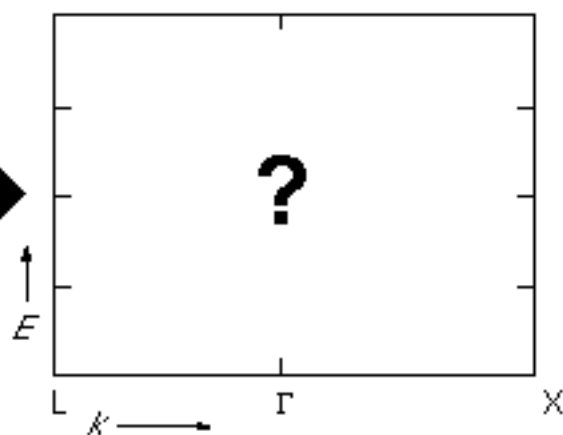


bandstructure

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dielectric function



INTRODUCTION

structure

?

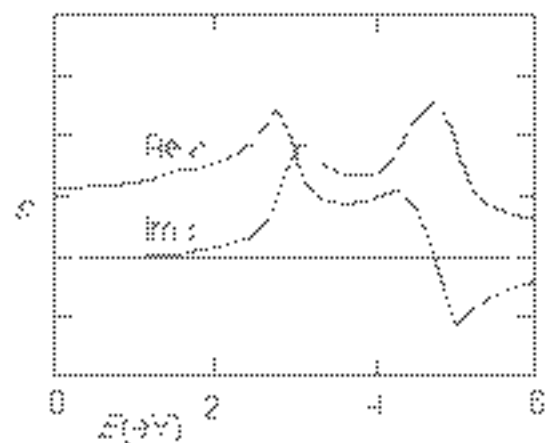
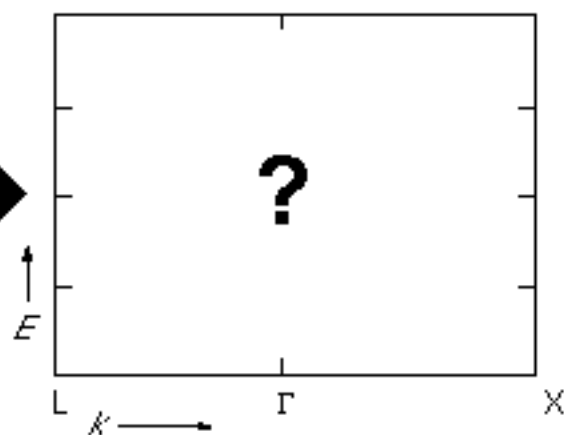


bandstructure

?



dielectric function



INTRODUCTION

structure

?



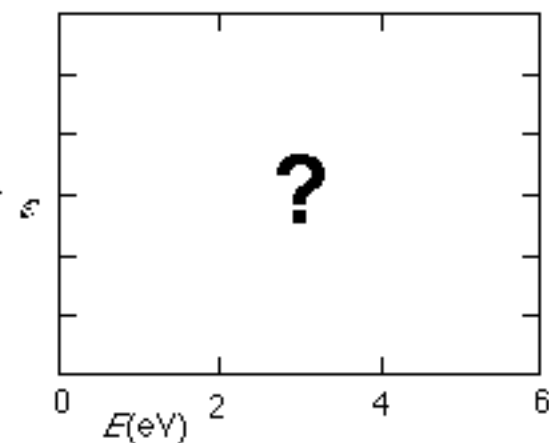
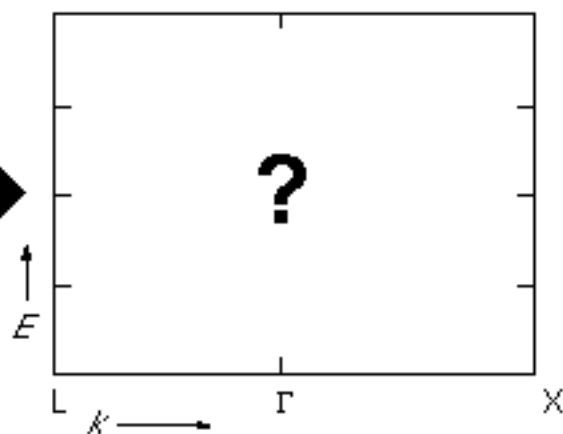
bandstructure

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dielectric function

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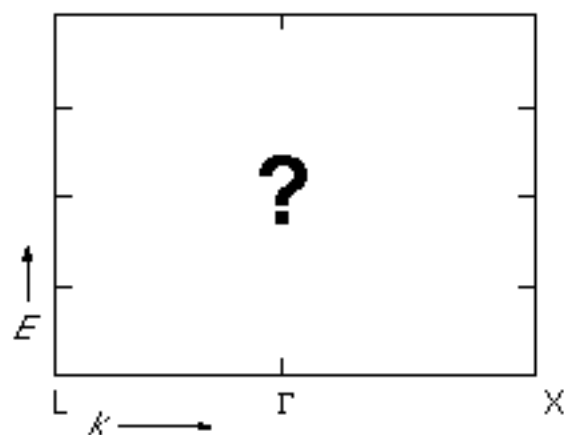


INTRODUCTION

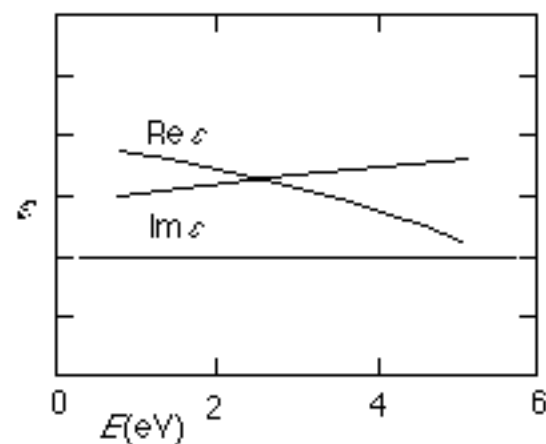
structure

?

bandstructure



dielectric function

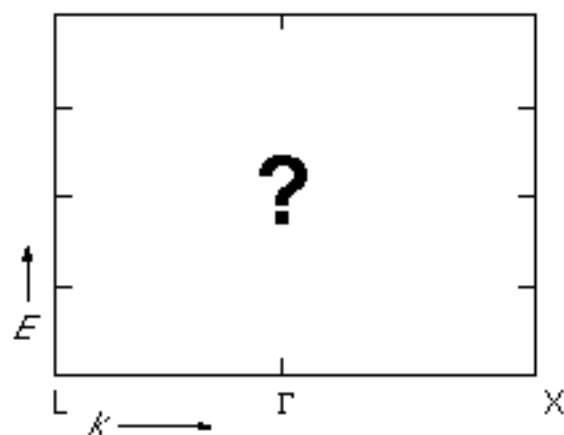


INTRODUCTION

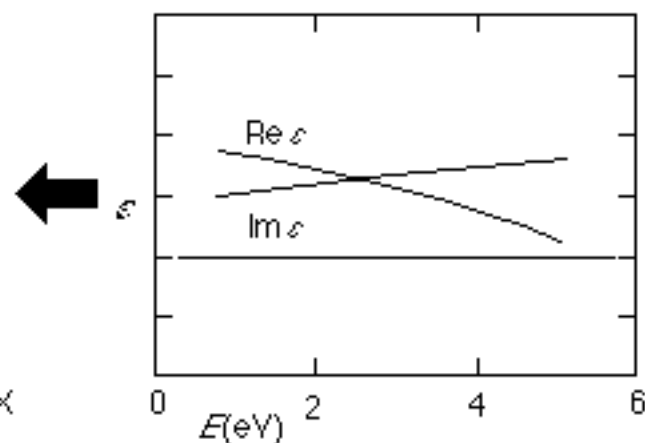
structure

?

bandstructure



dielectric function



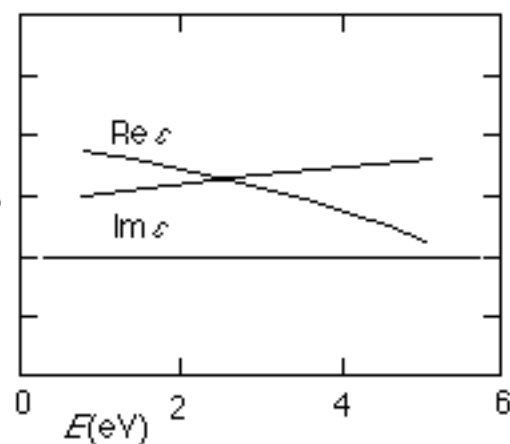
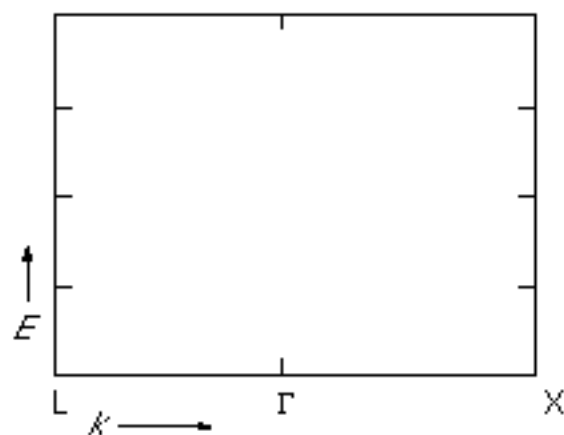
INTRODUCTION

structure

bandstructure

dielectric function

?



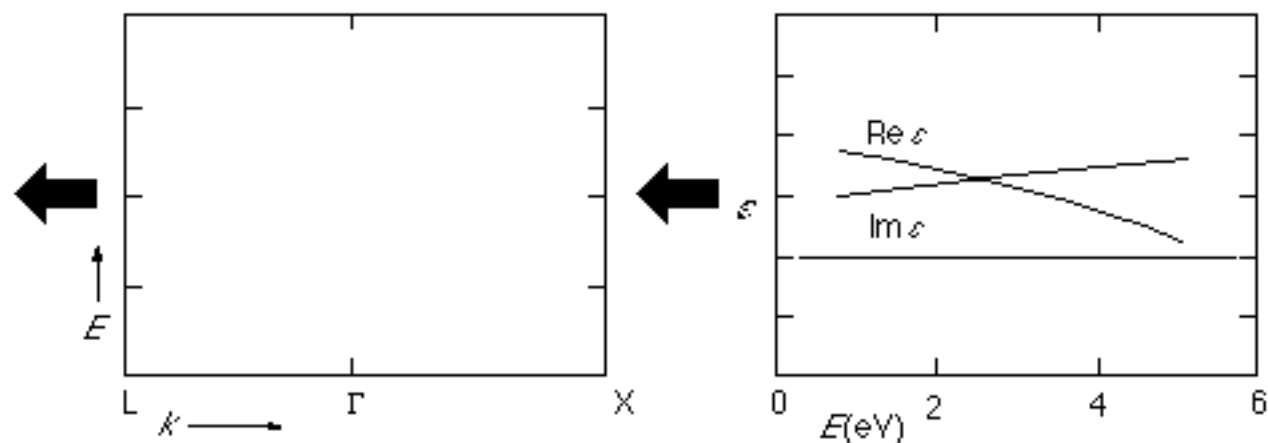
INTRODUCTION

structure

bandstructure

dielectric function

?

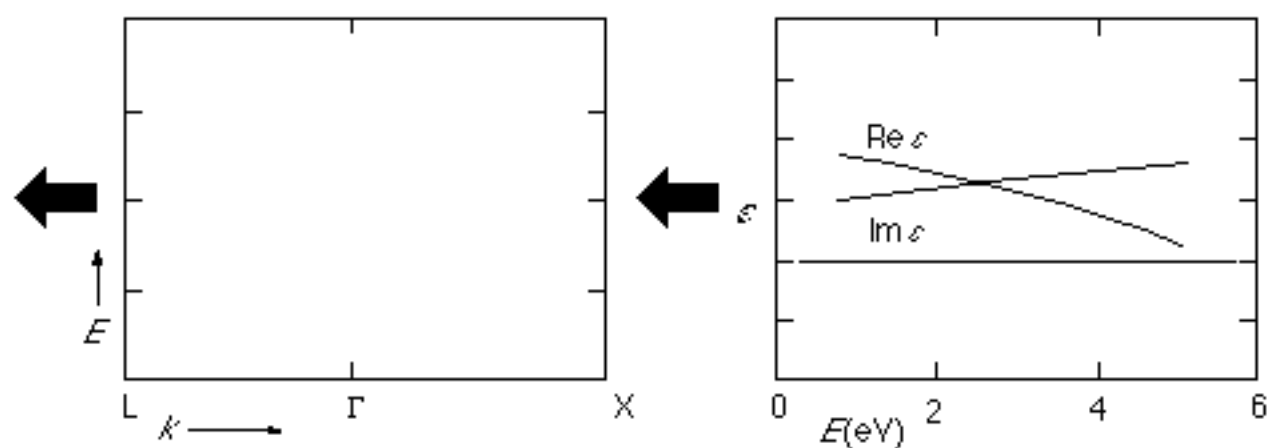


INTRODUCTION

structure

bandstructure

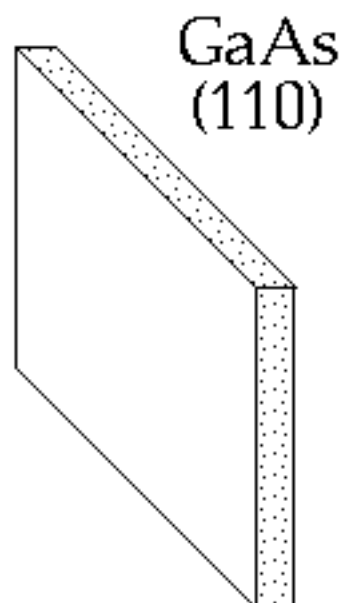
dielectric function



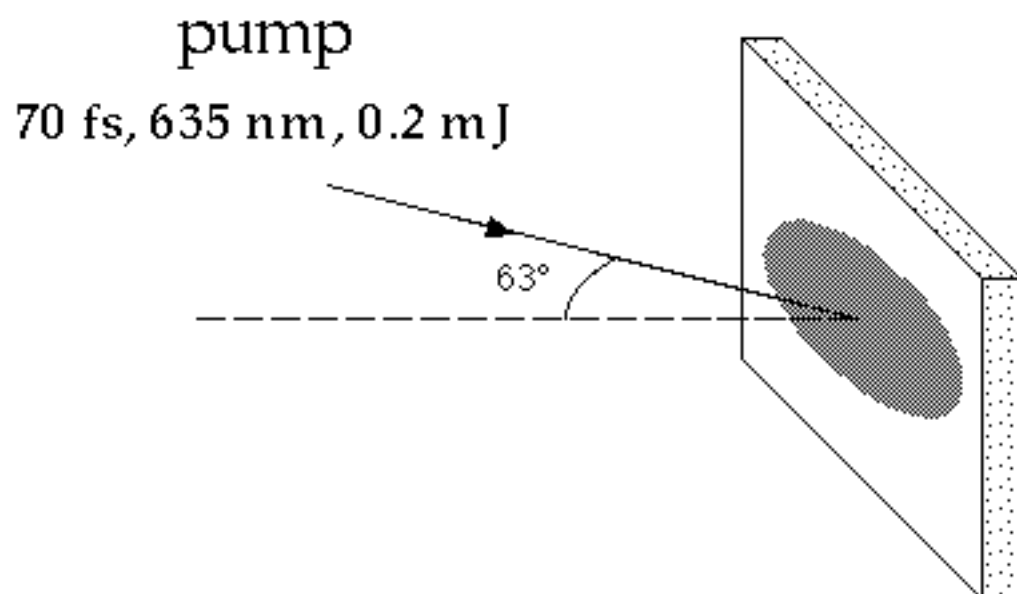
- ① Method
- ② Results
- ③ Discussion



2.2 eV DIELECTRIC CONSTANT



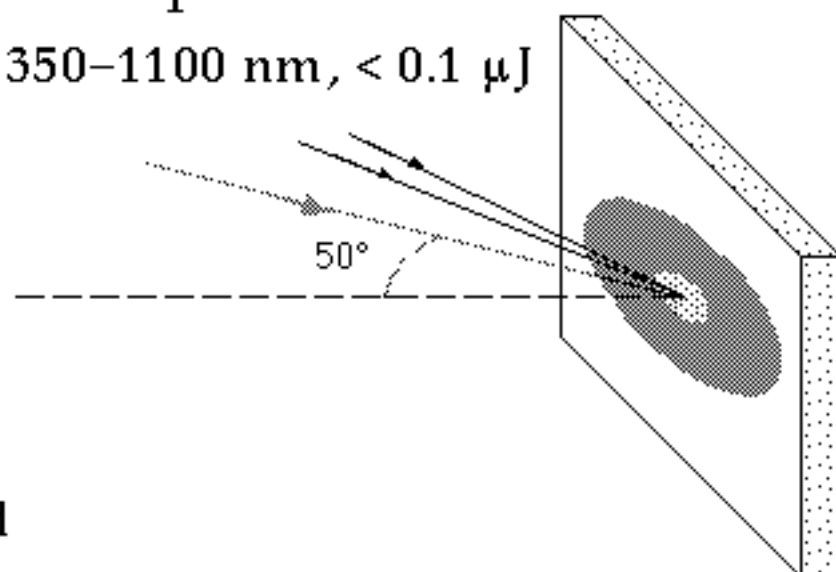
2.2 eV DIELECTRIC CONSTANT



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probes

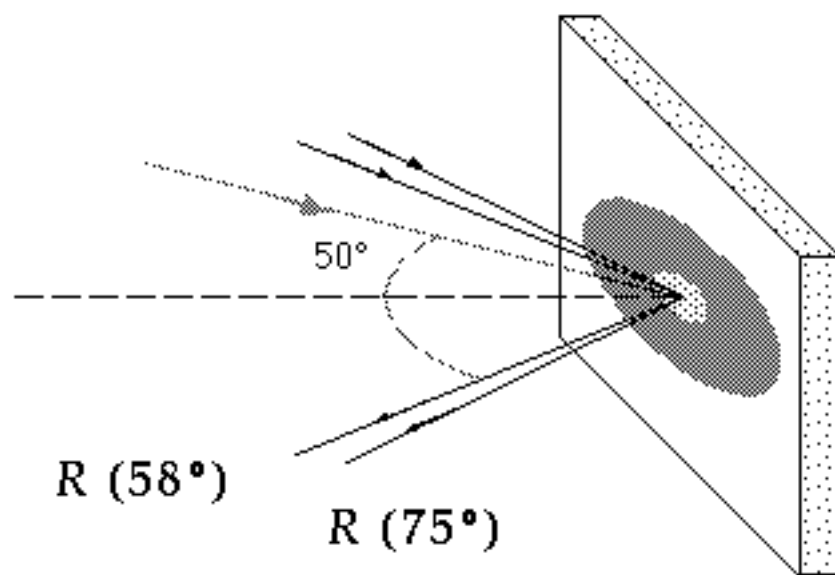
350–1100 nm, $< 0.1 \mu\text{J}$



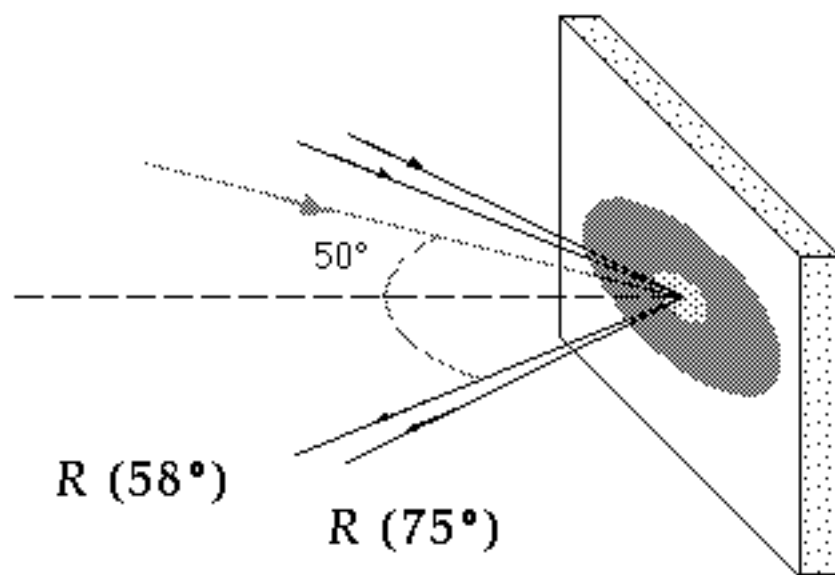
all beams
p-polarized



2.2 eV DIELECTRIC CONSTANT



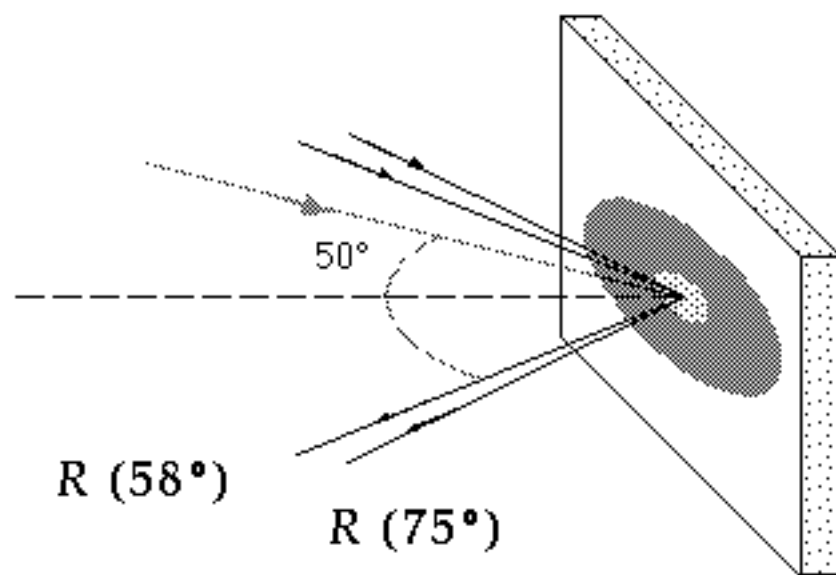
2.2 eV DIELECTRIC CONSTANT



Fresnel
equations



2.2 eV DIELECTRIC CONSTANT

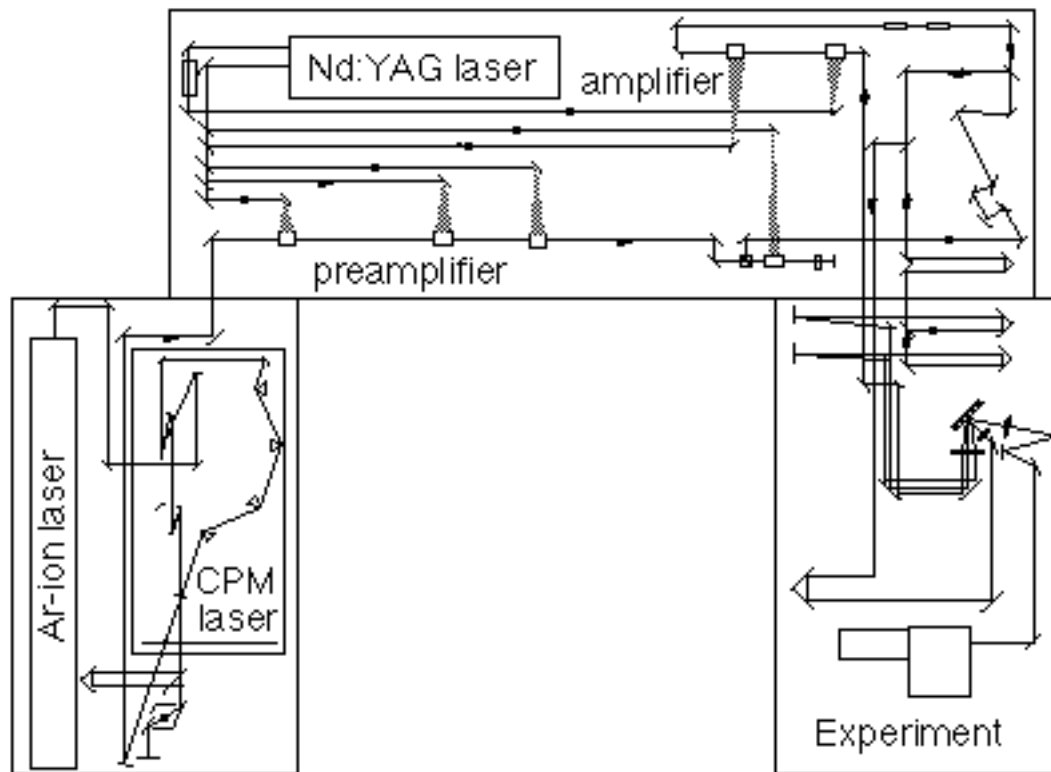


↓
Fresnel
equations

→ $\text{Re } \epsilon(\omega), \text{Im } \epsilon(\omega)$



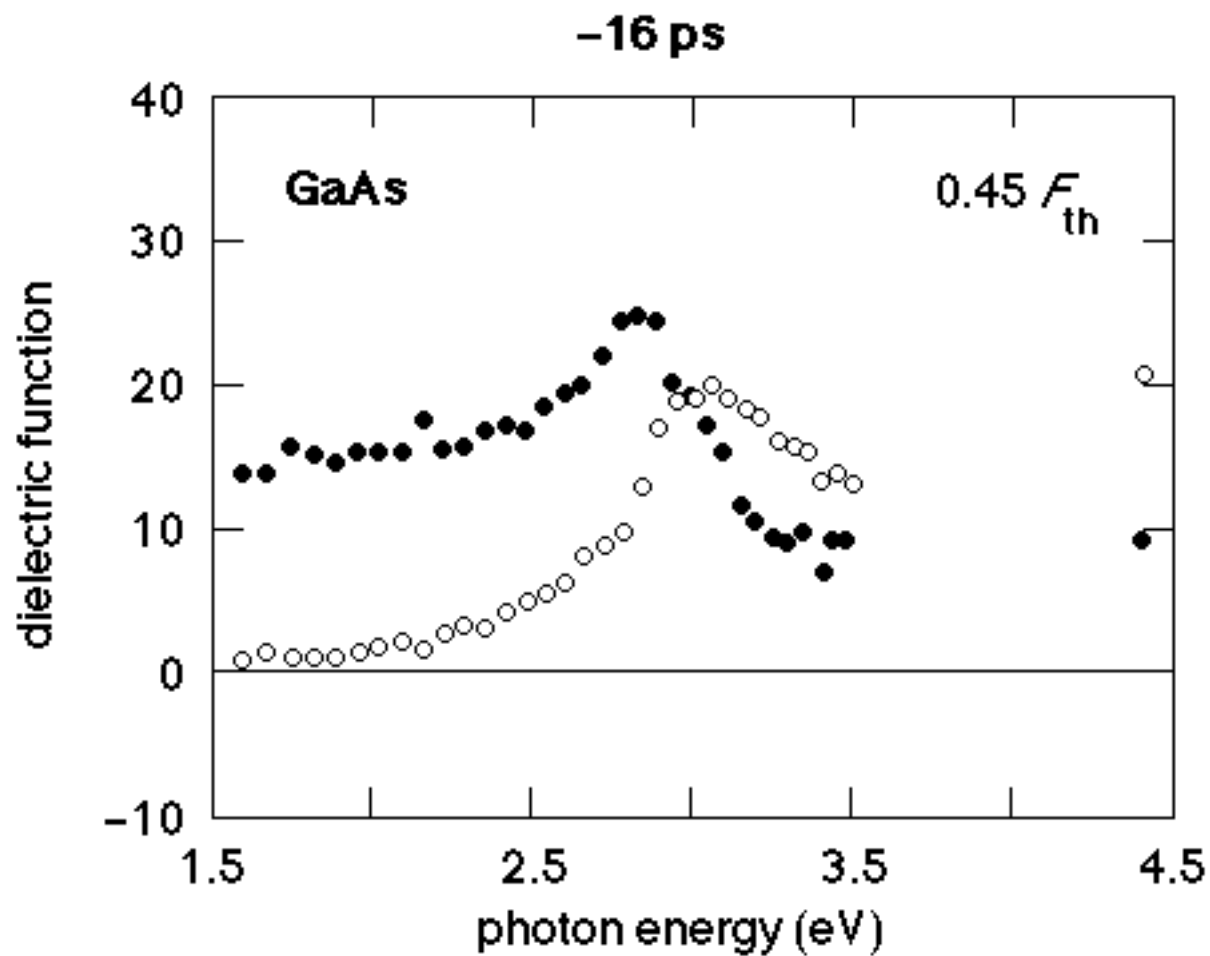
SETUP



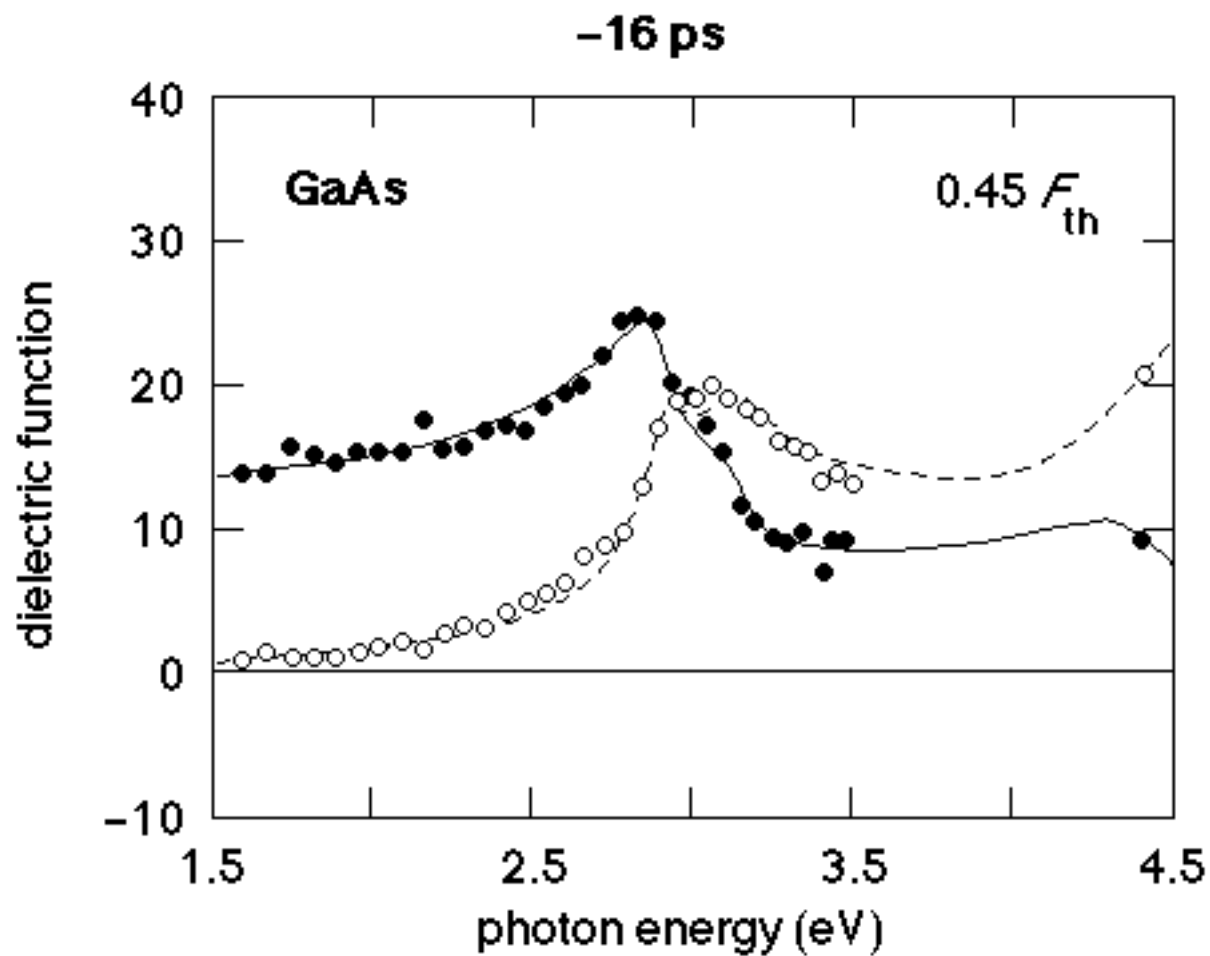
- ➊ Method
- ➋ Results
- ➌ Discussion



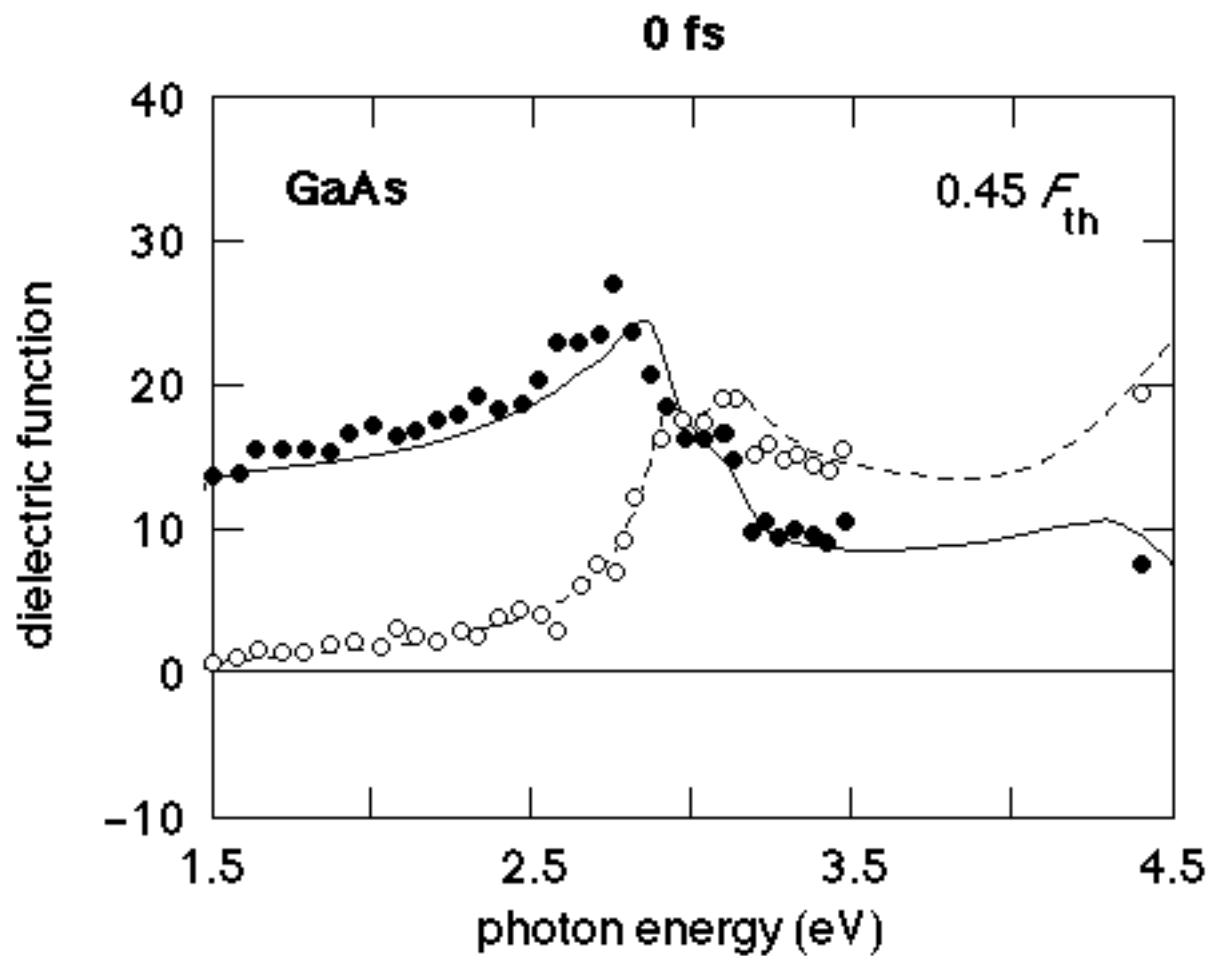
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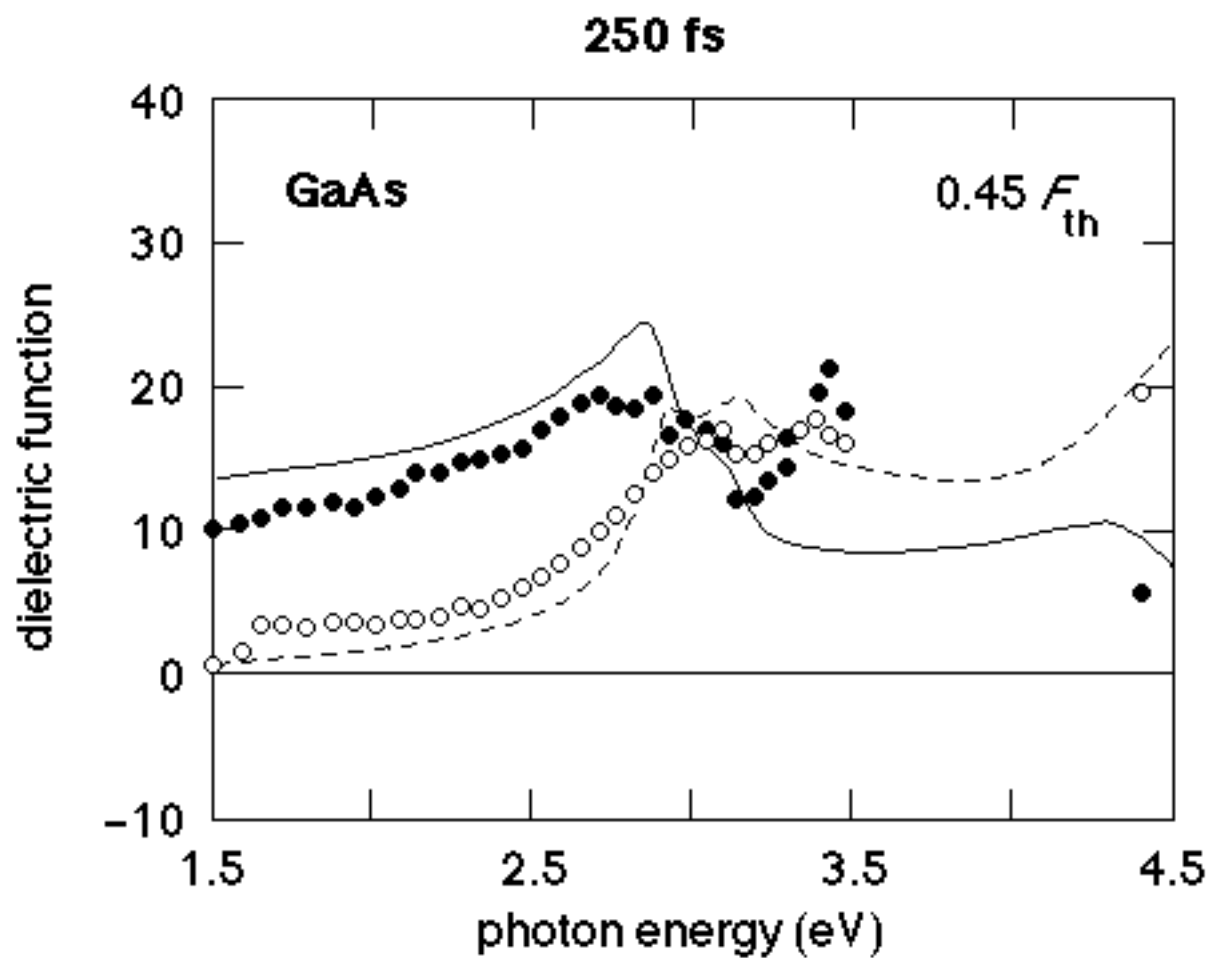
LOW FLUENCE DATA



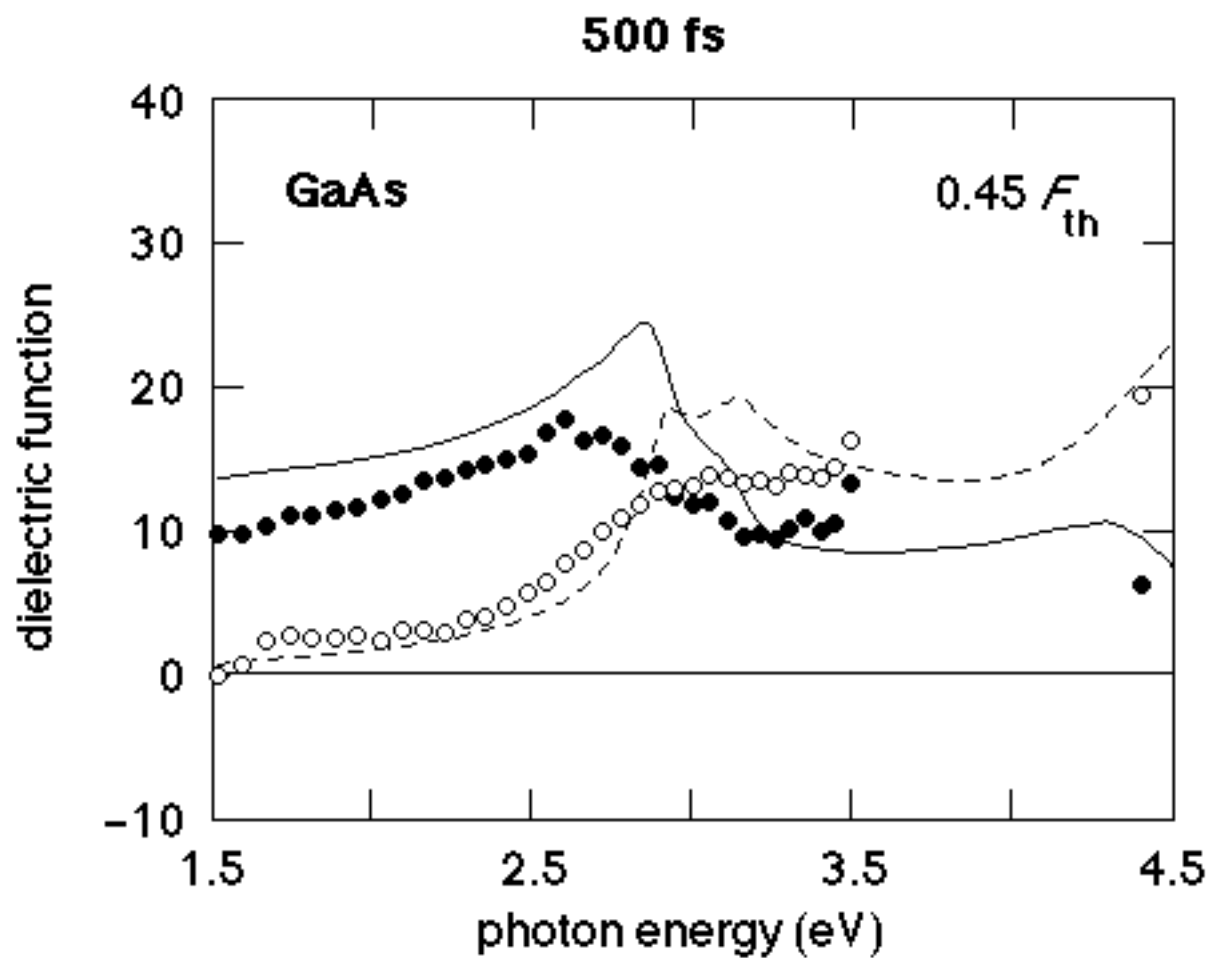
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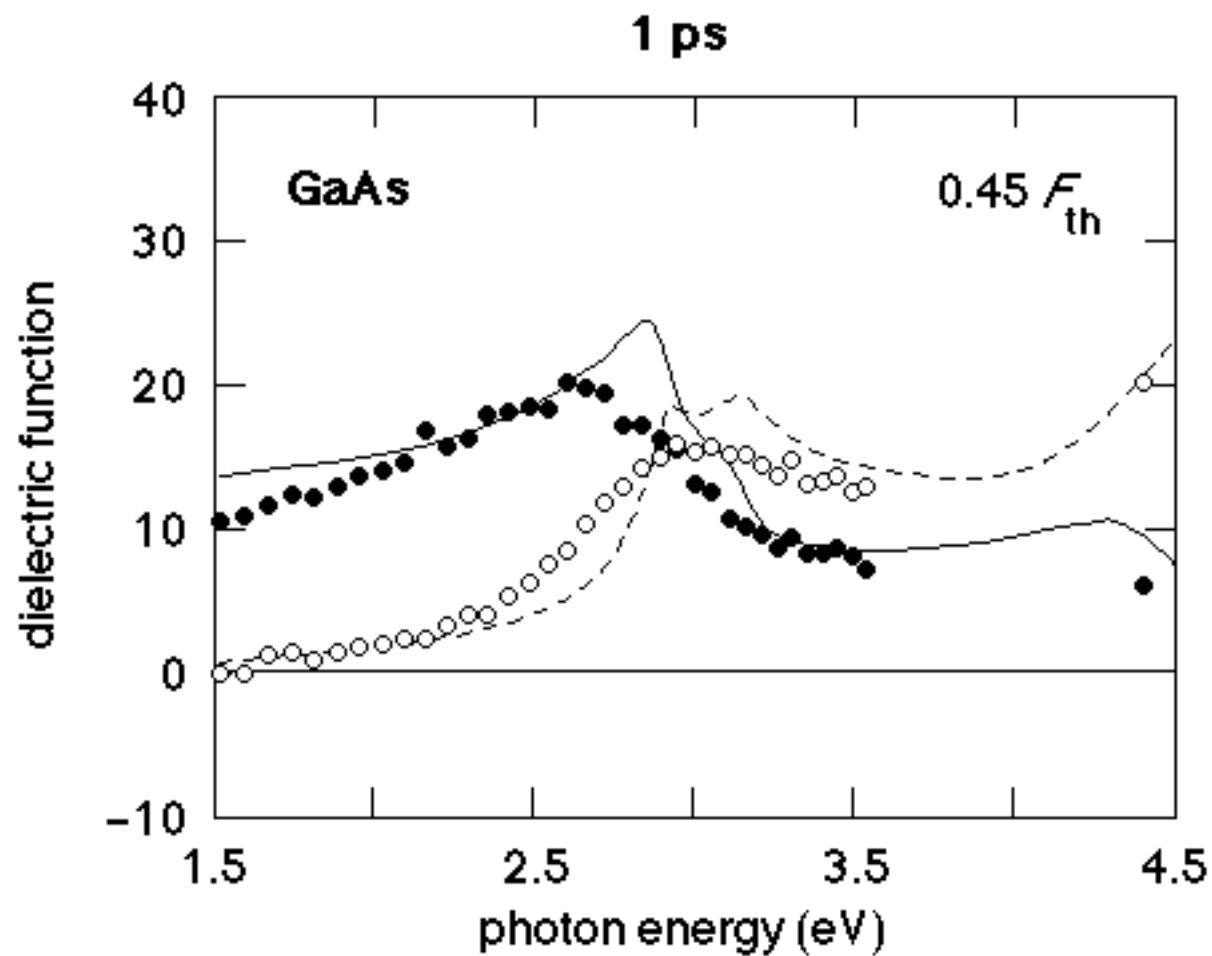
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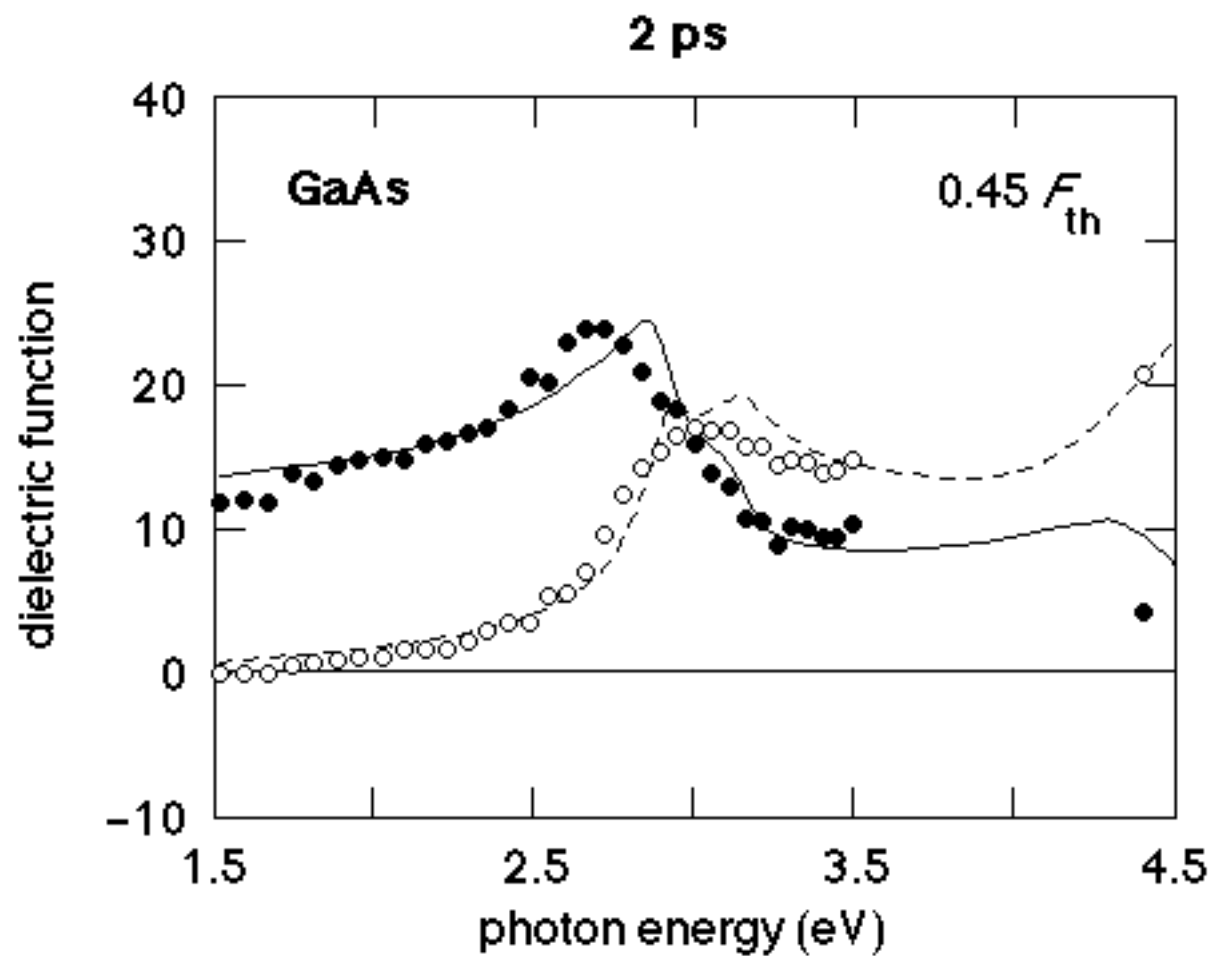
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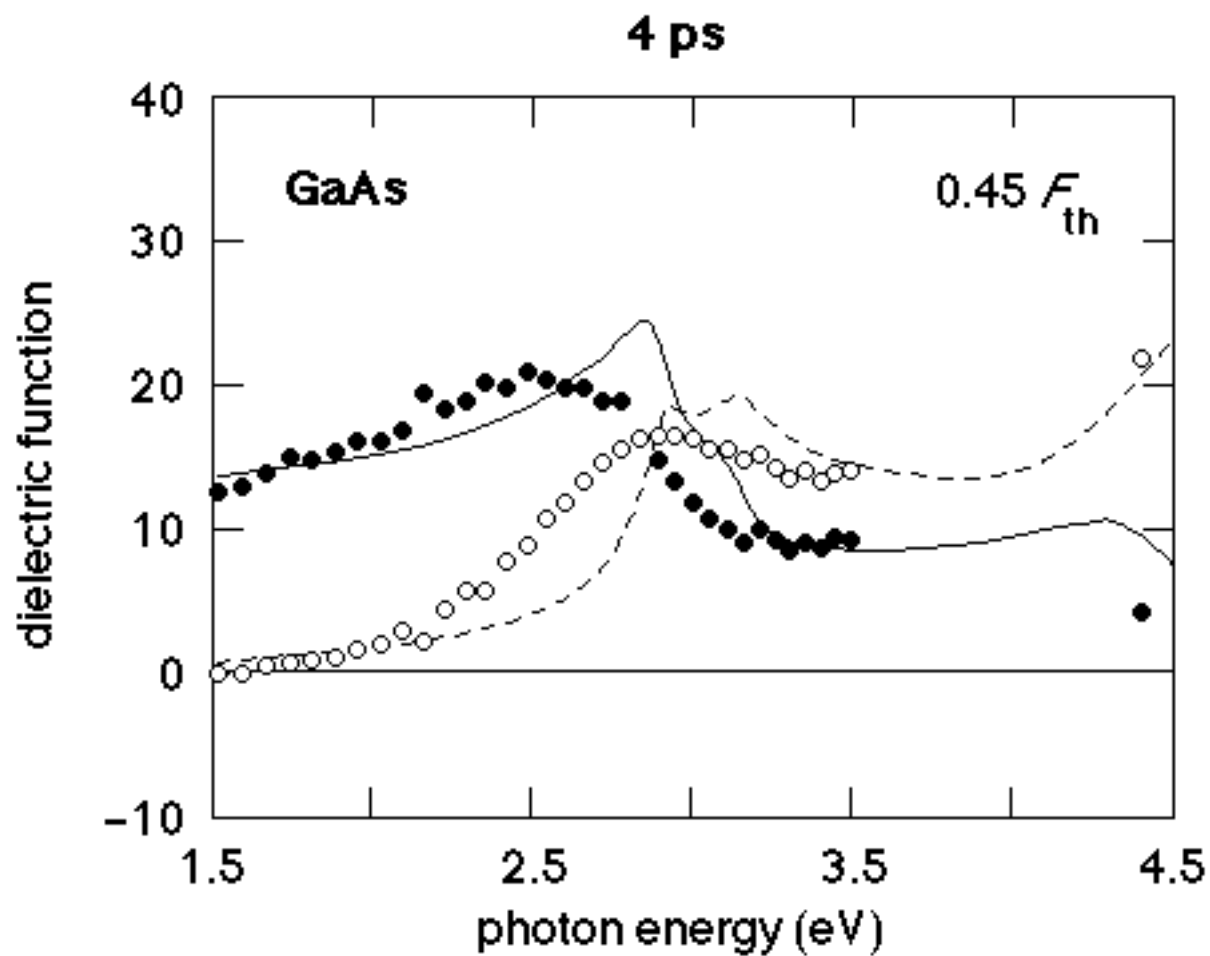
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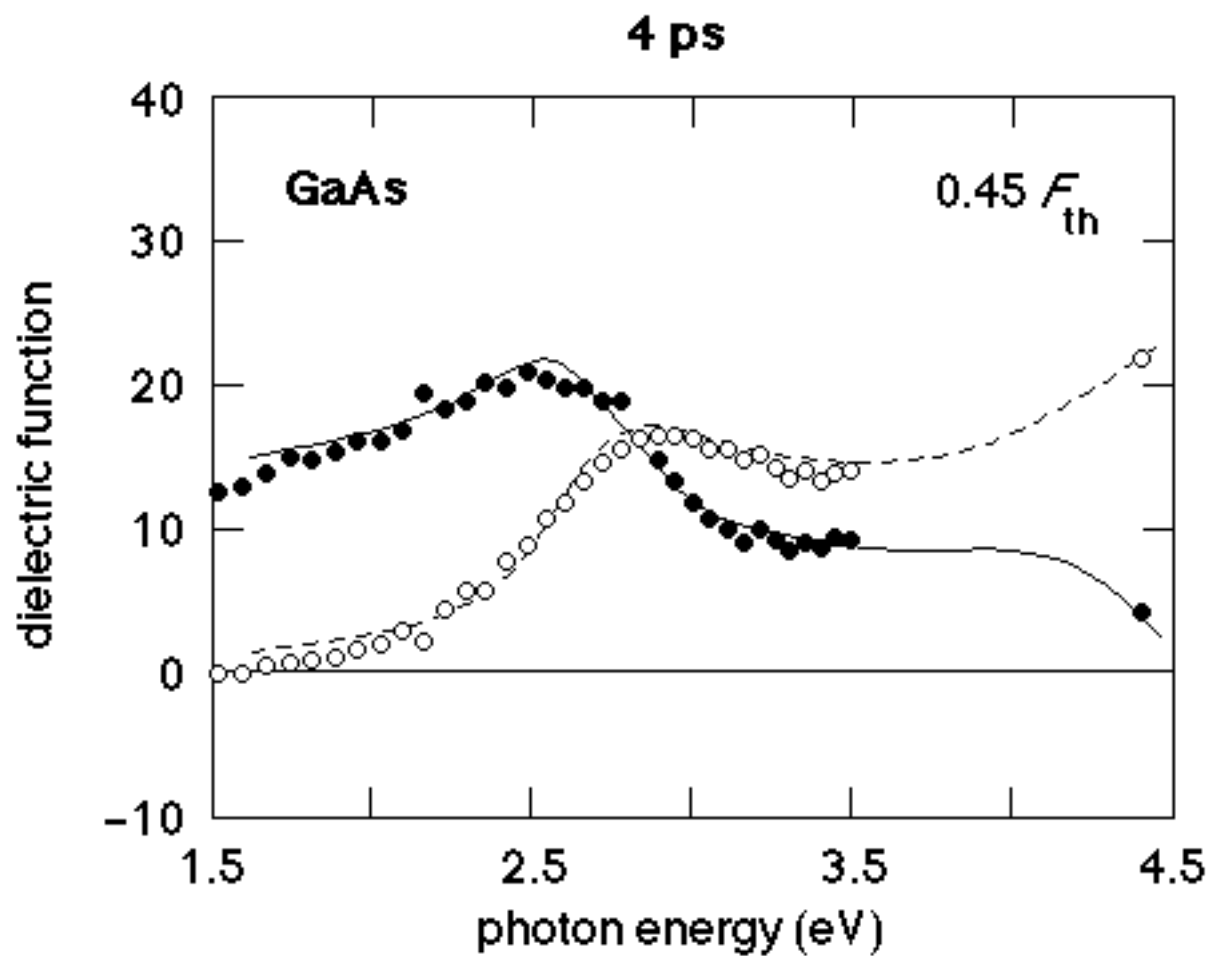
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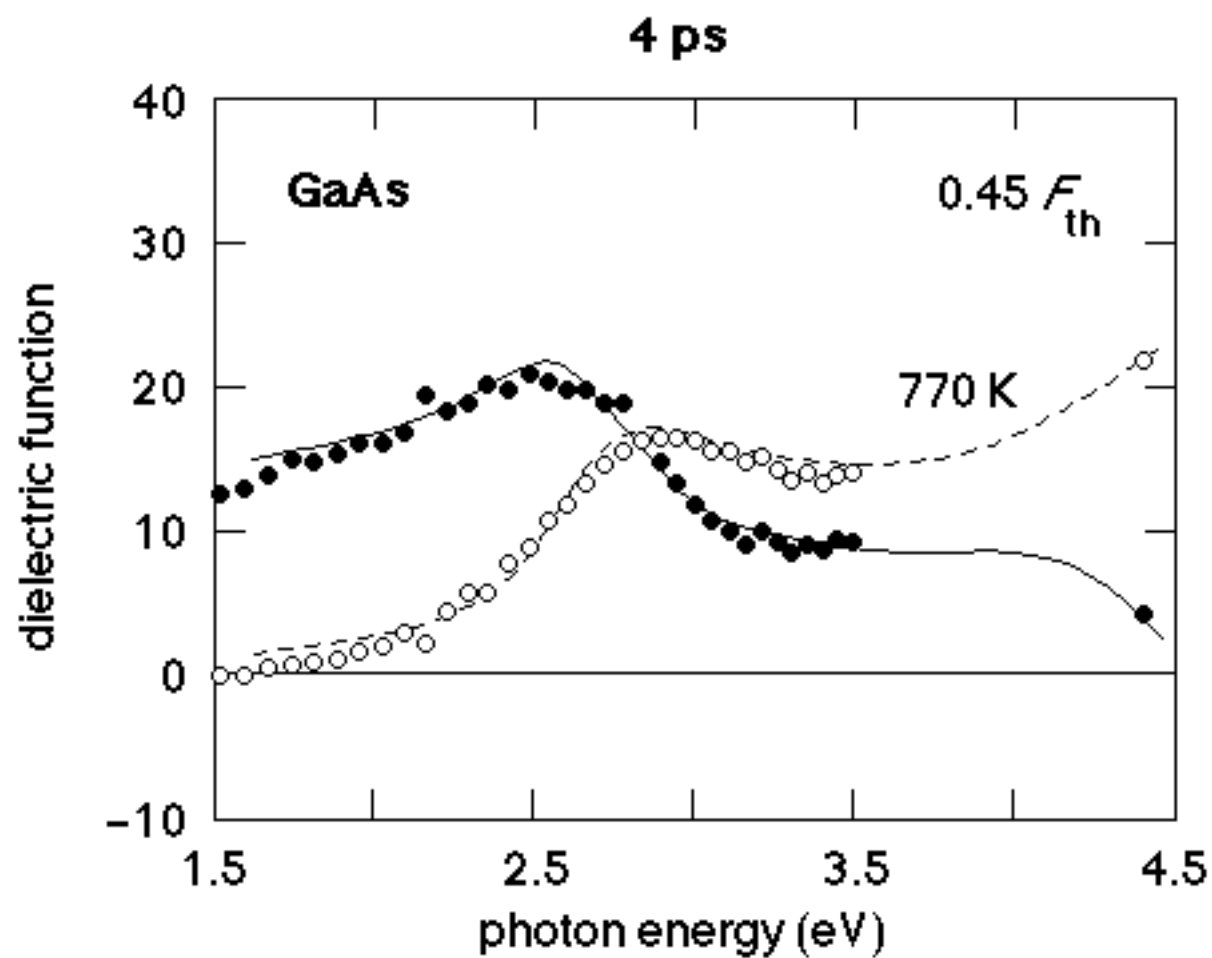
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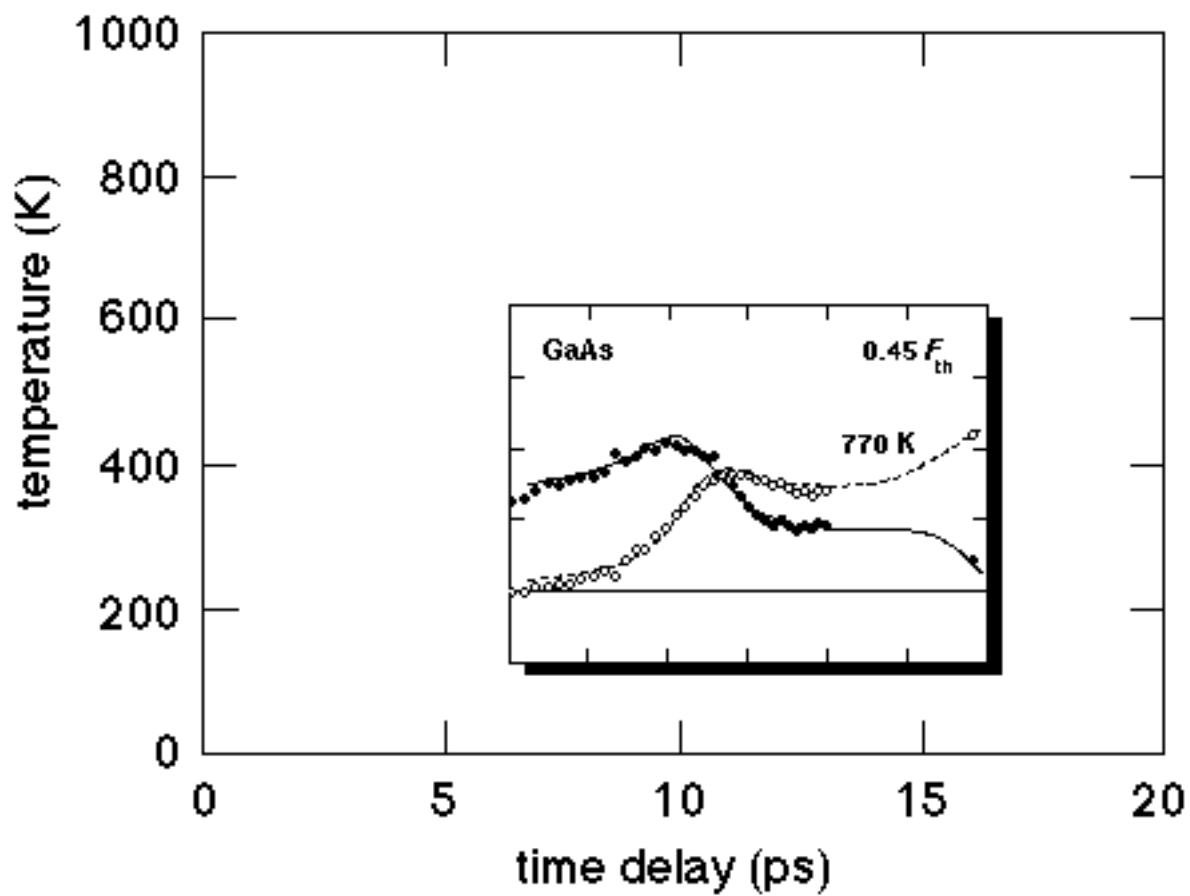
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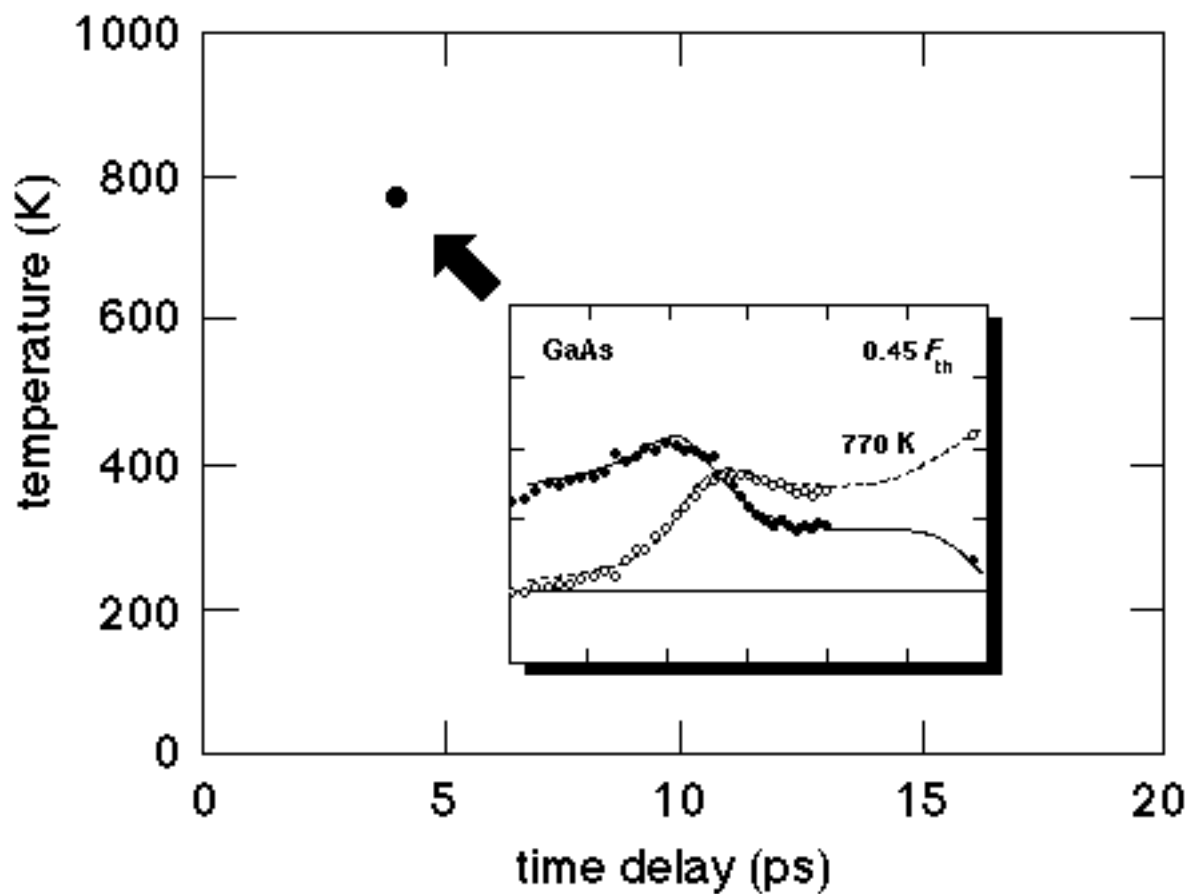
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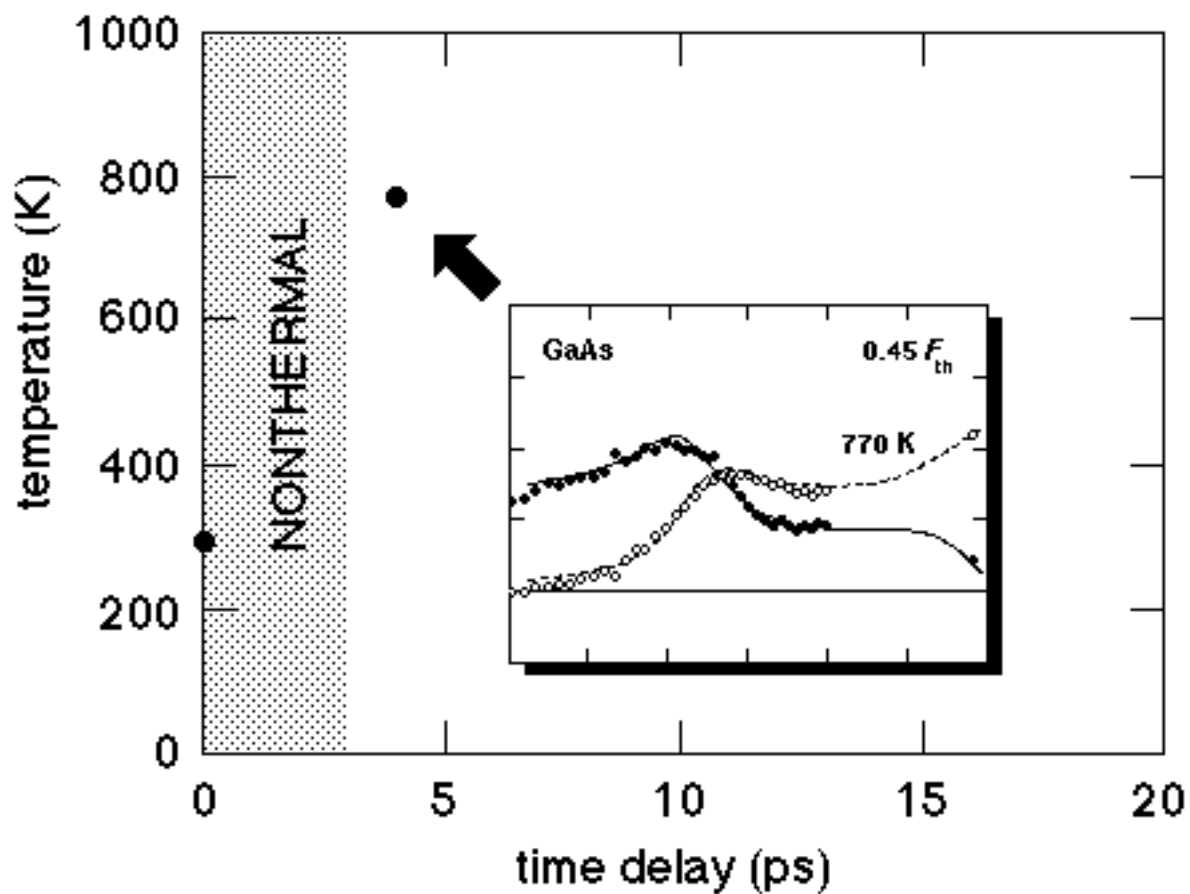
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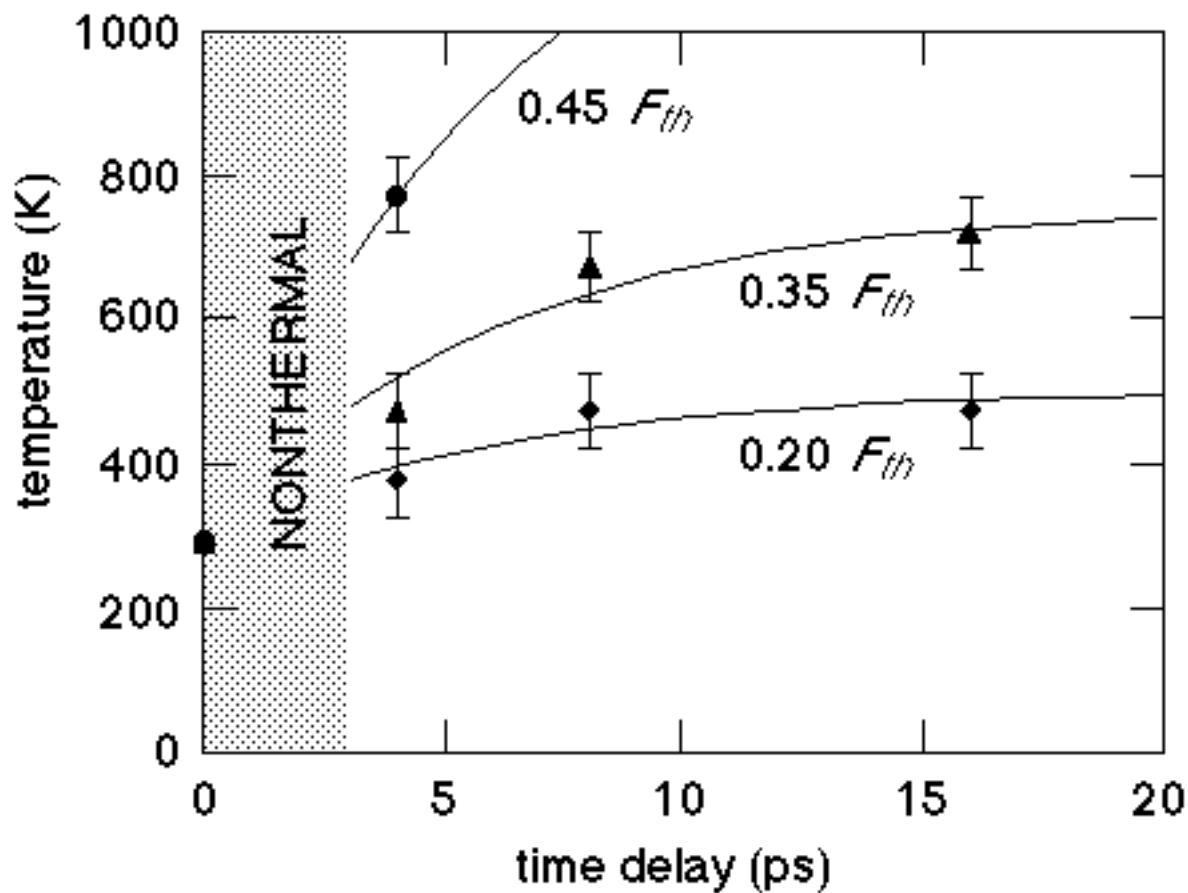
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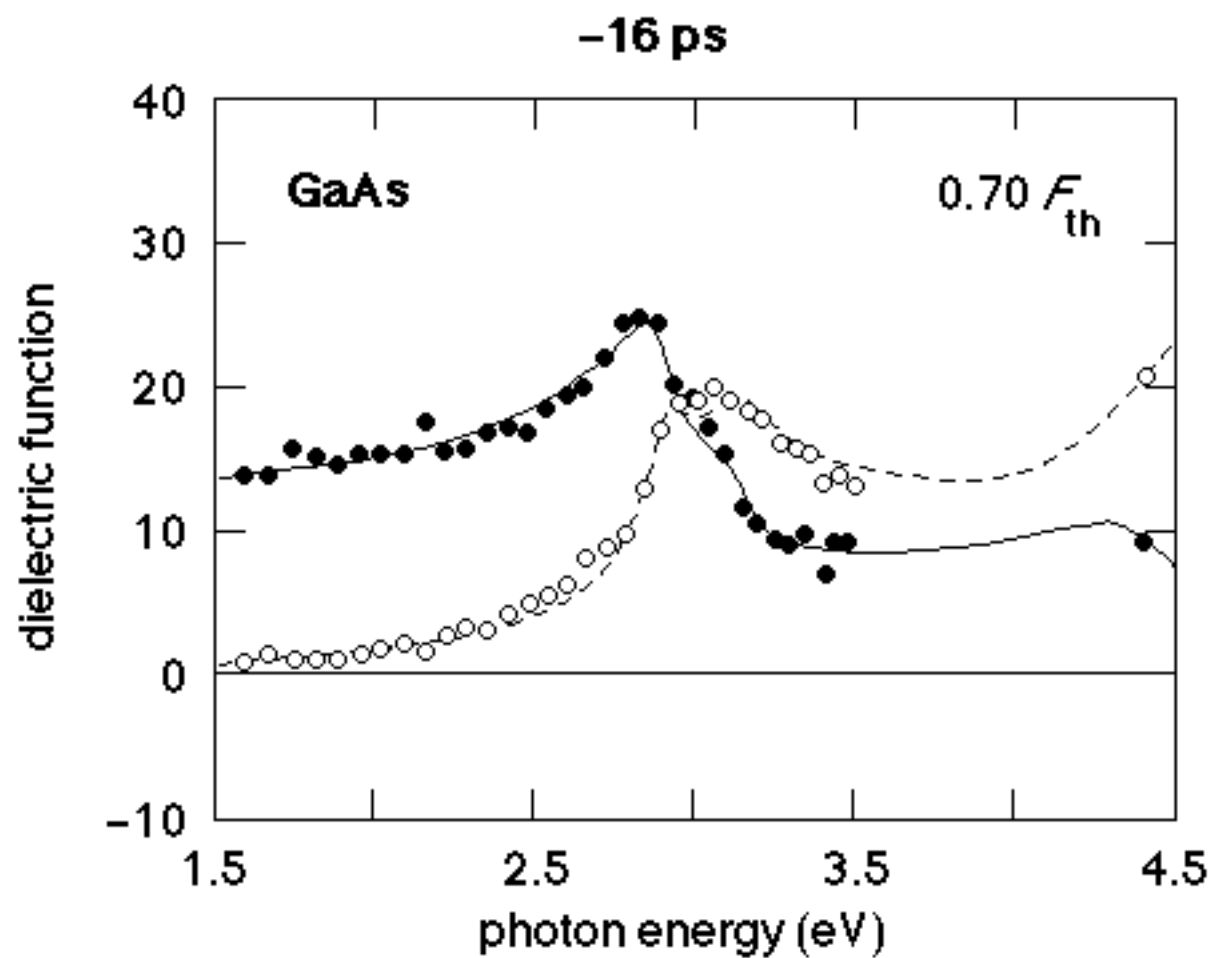
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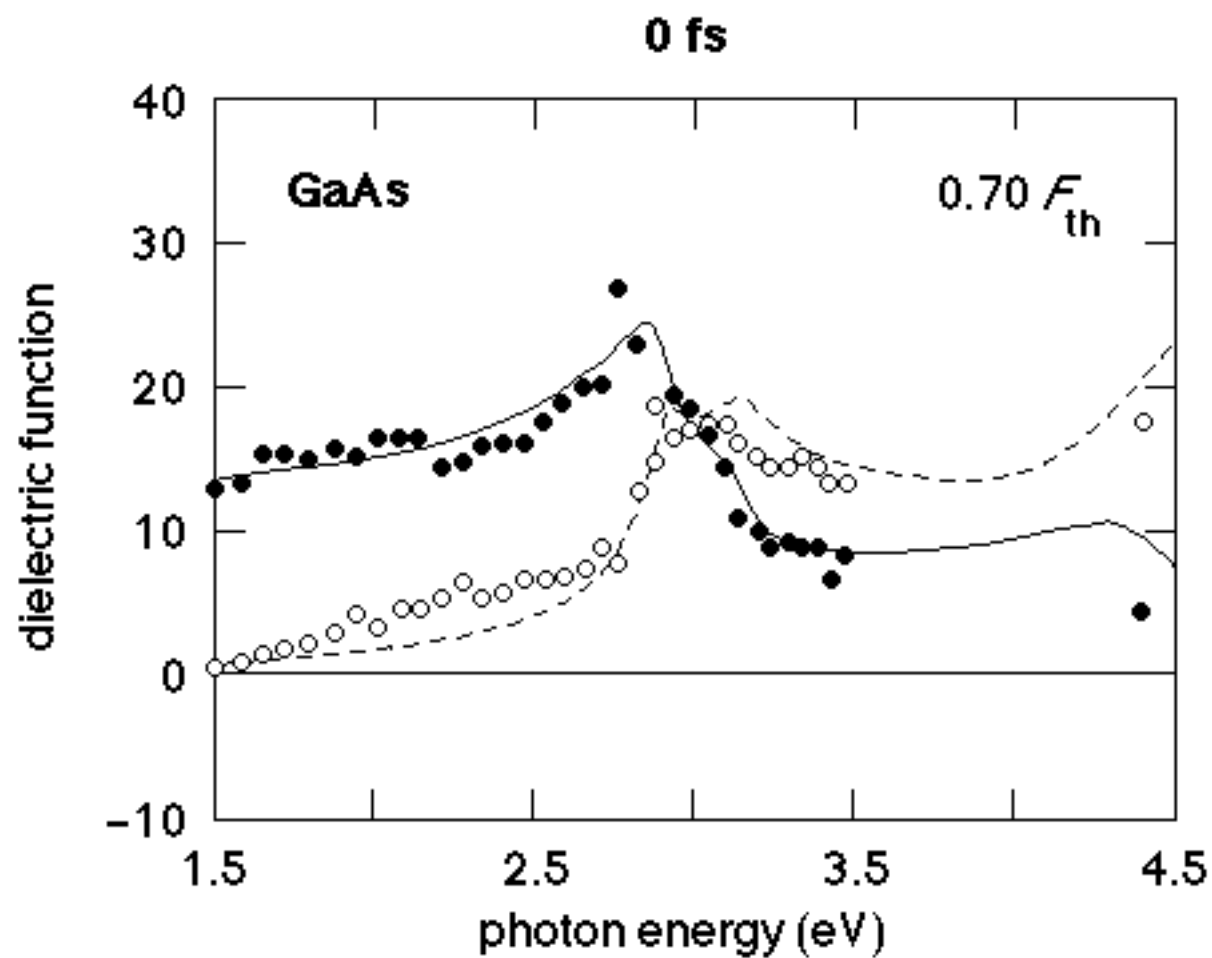
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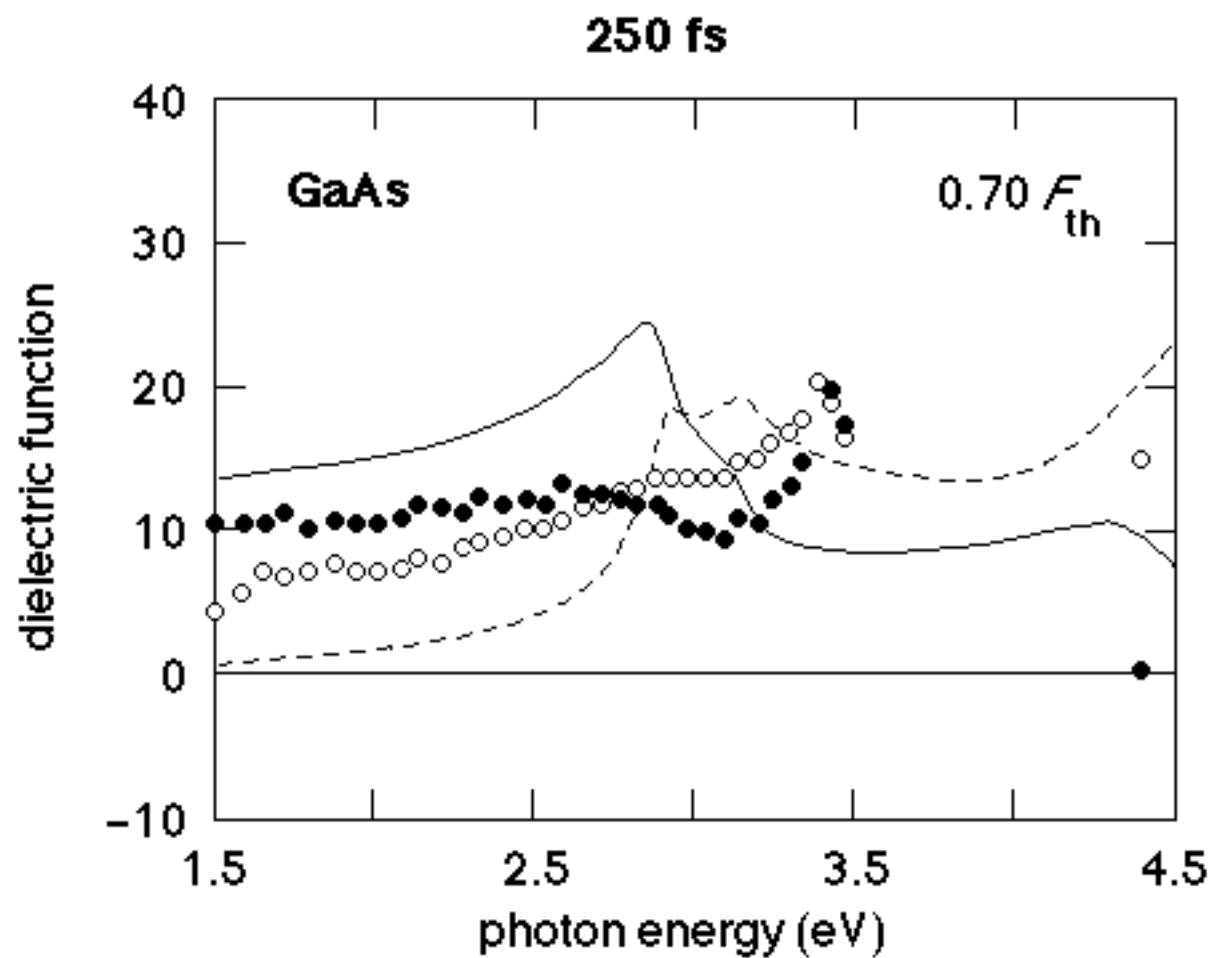
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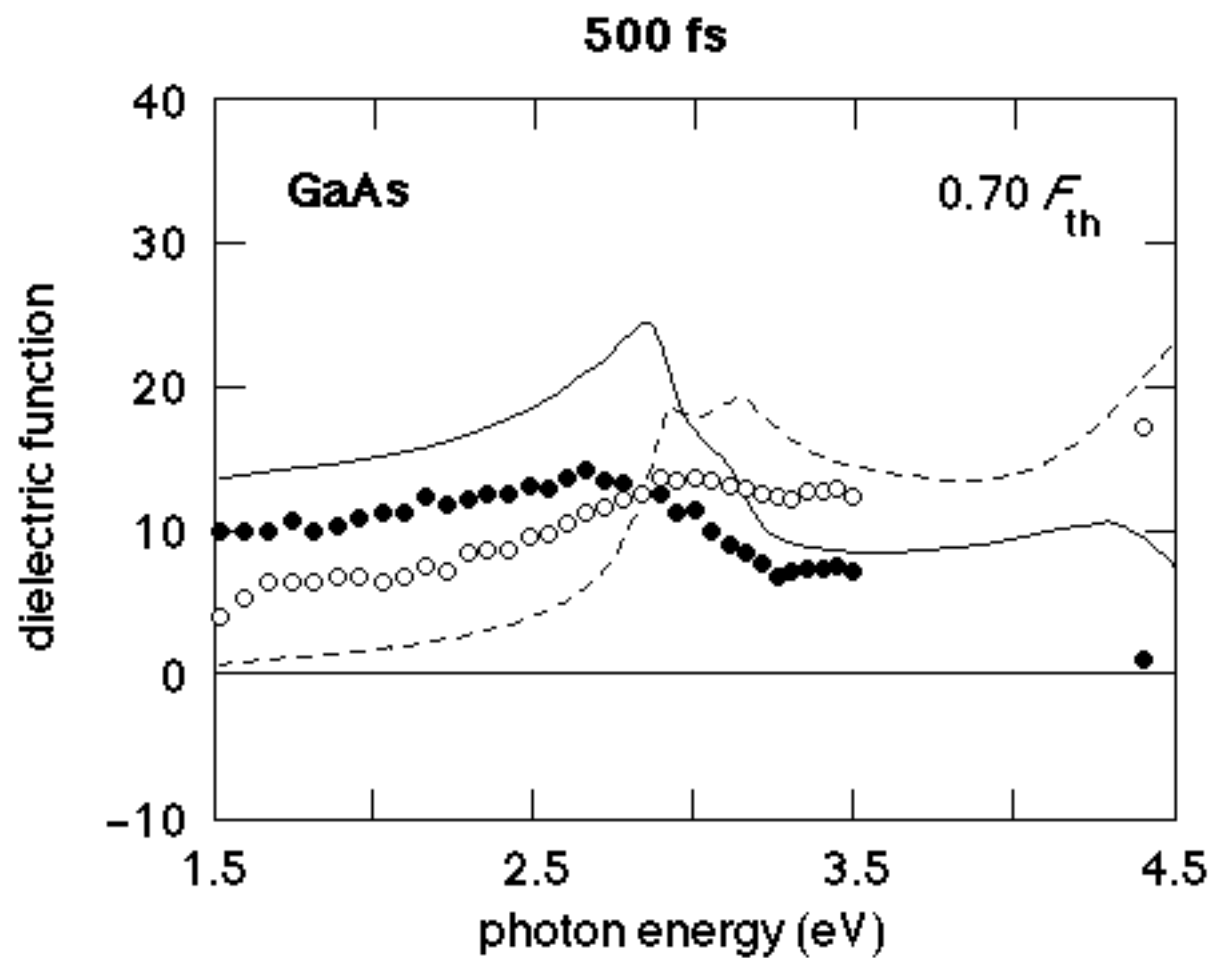
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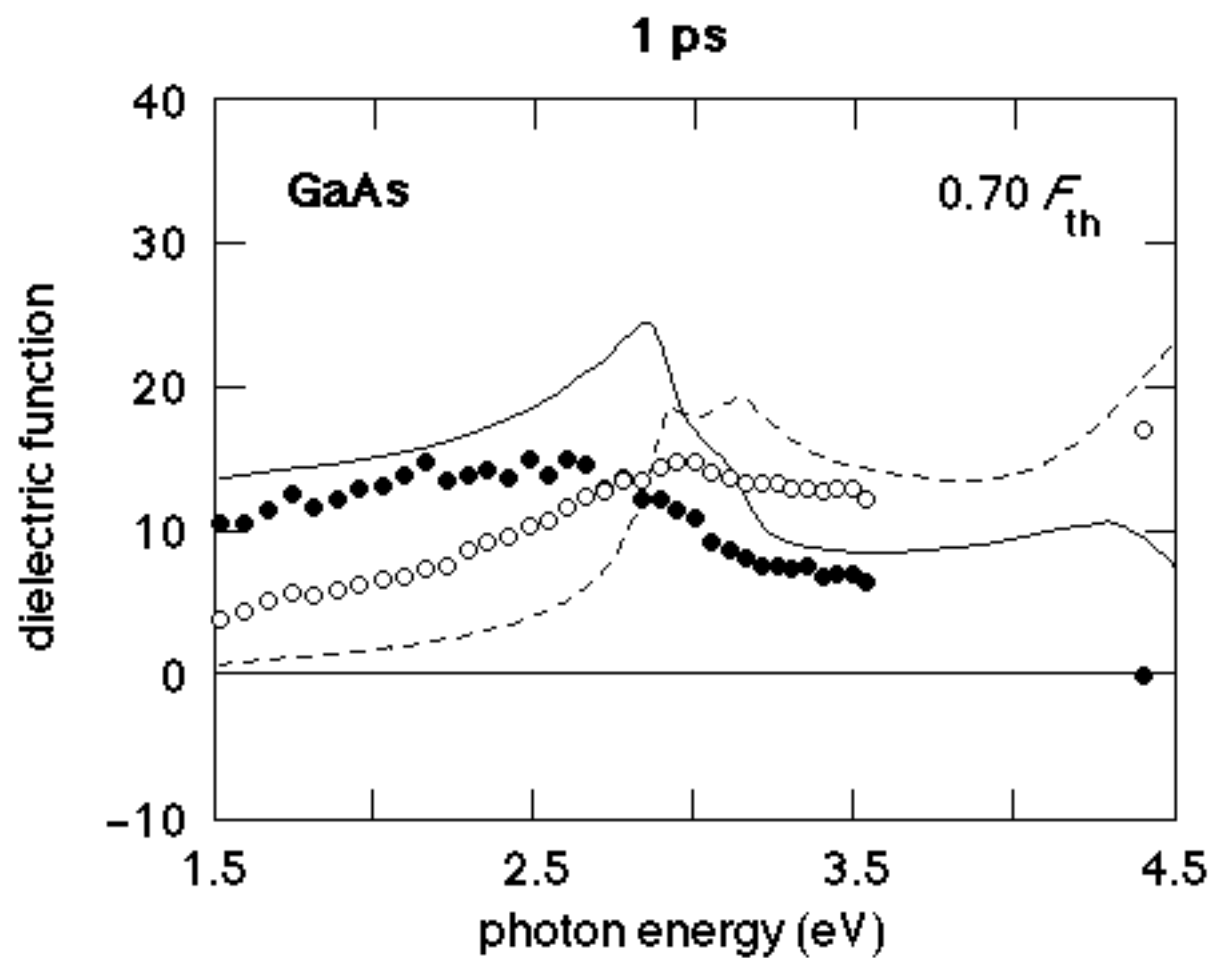
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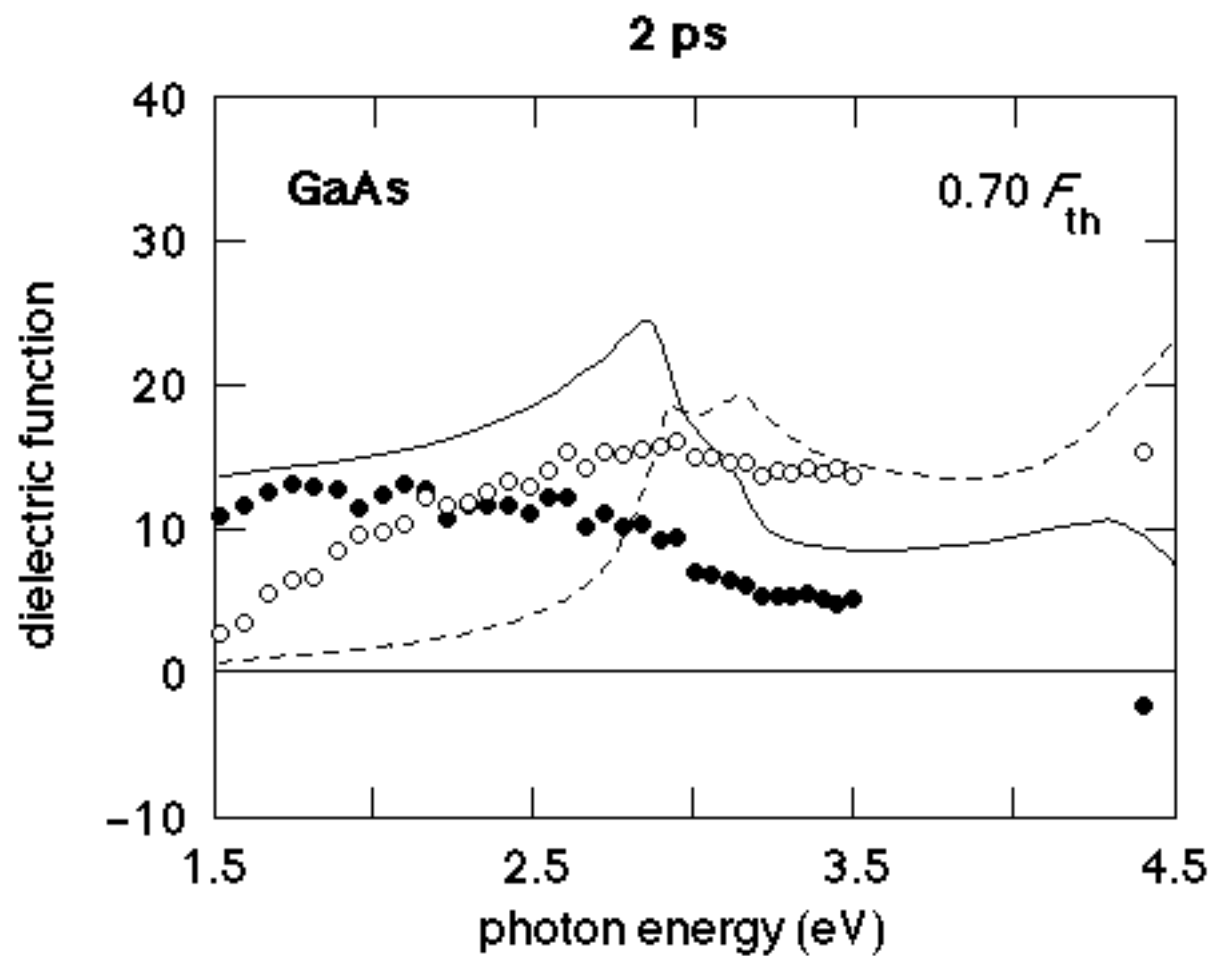
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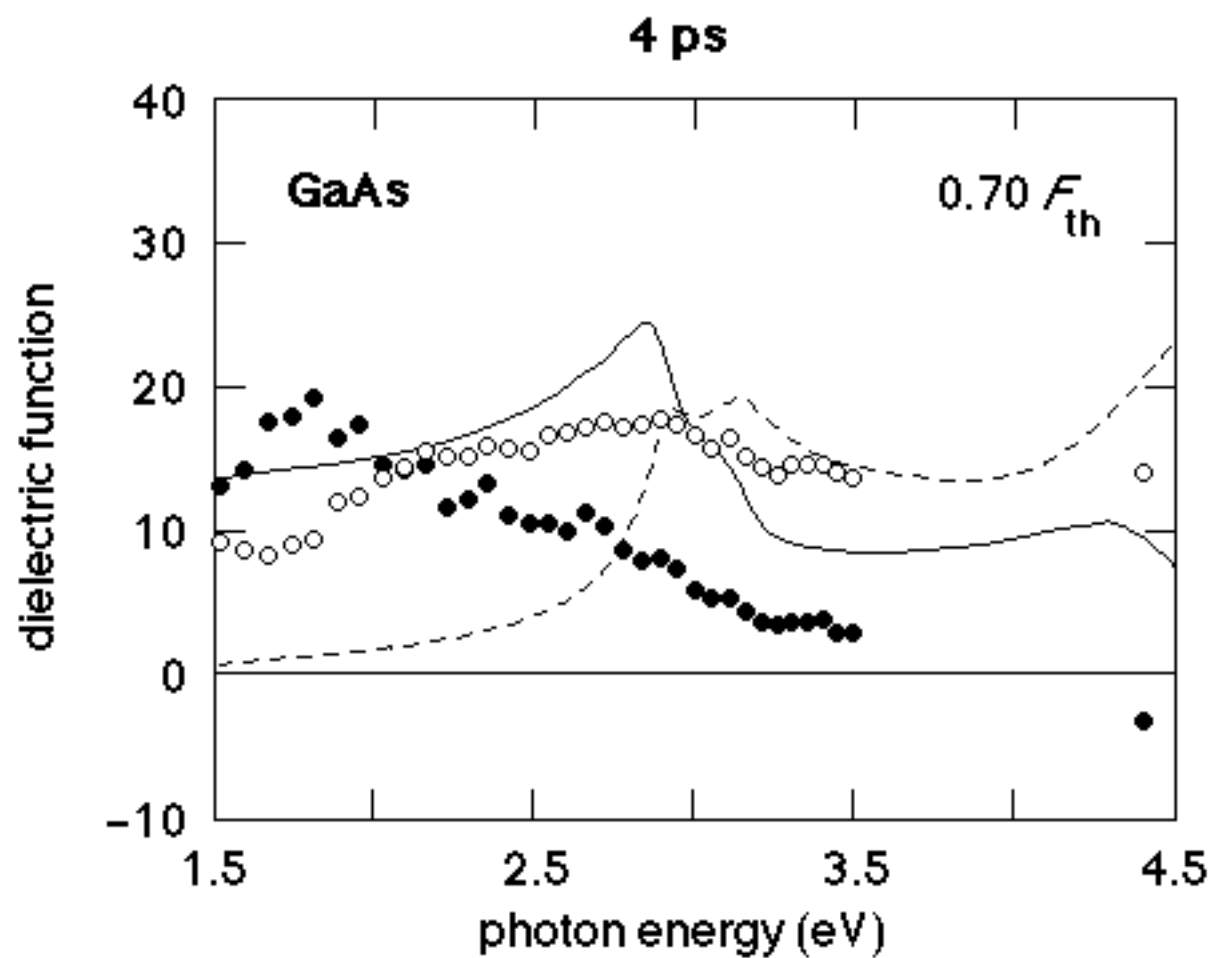
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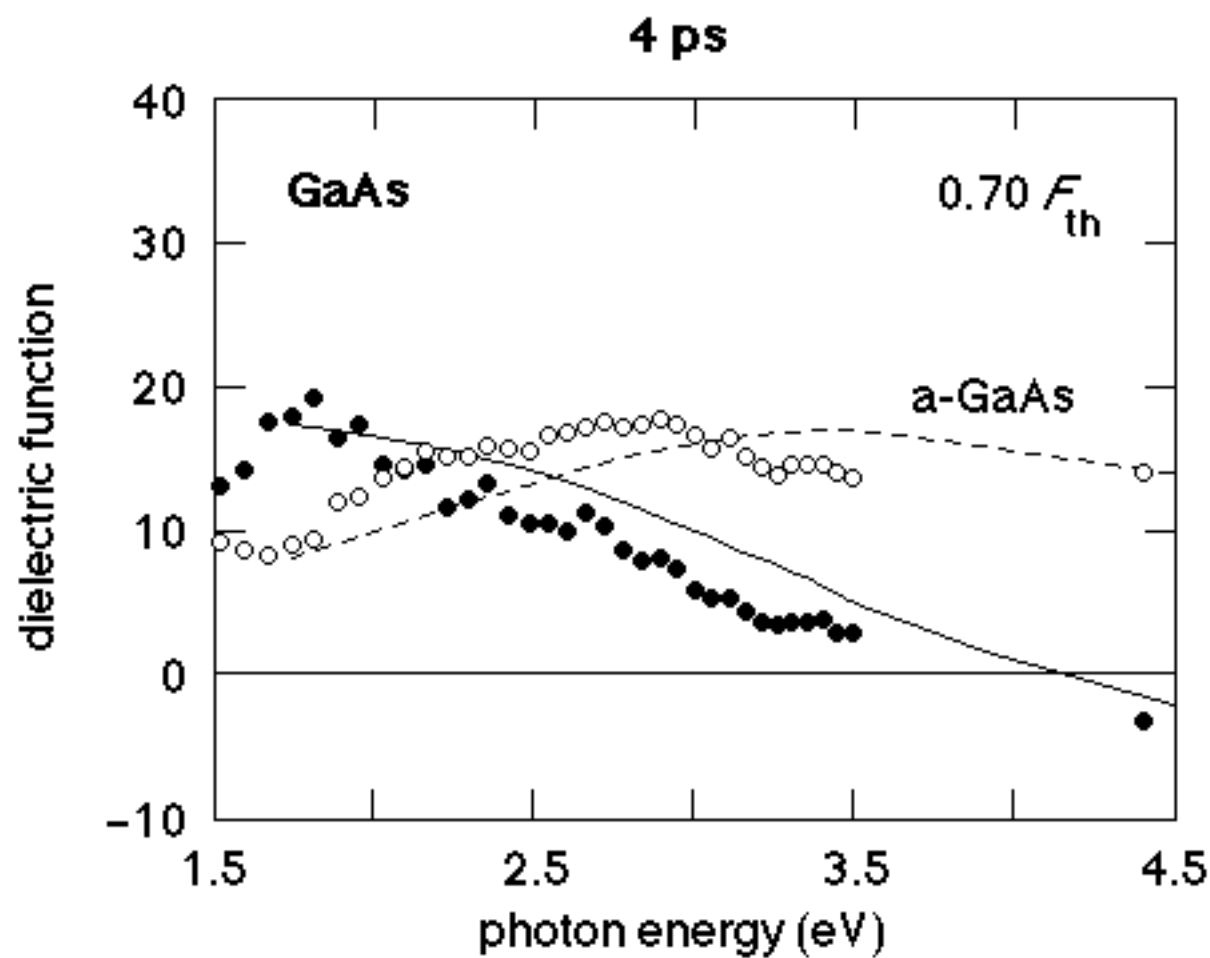
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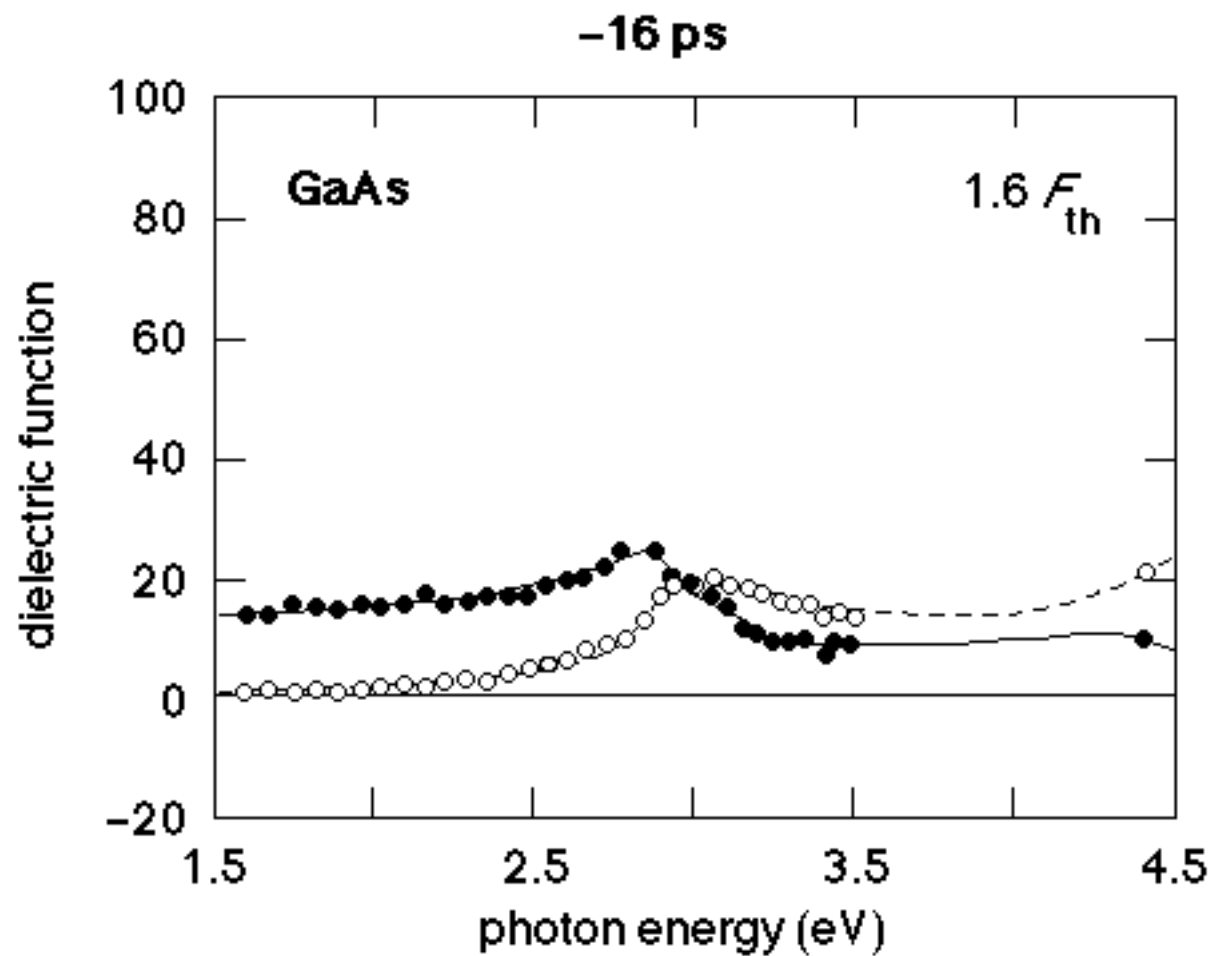
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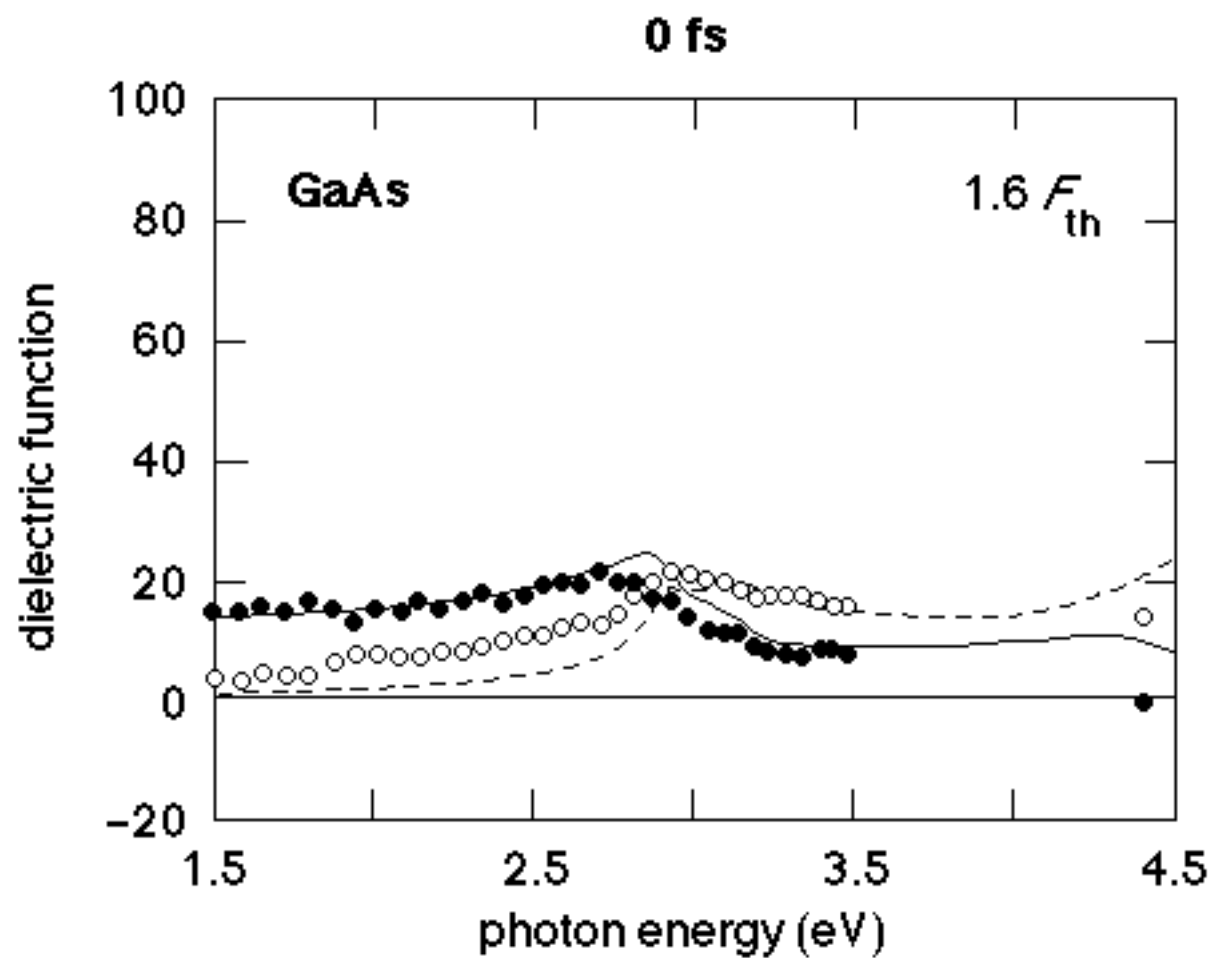
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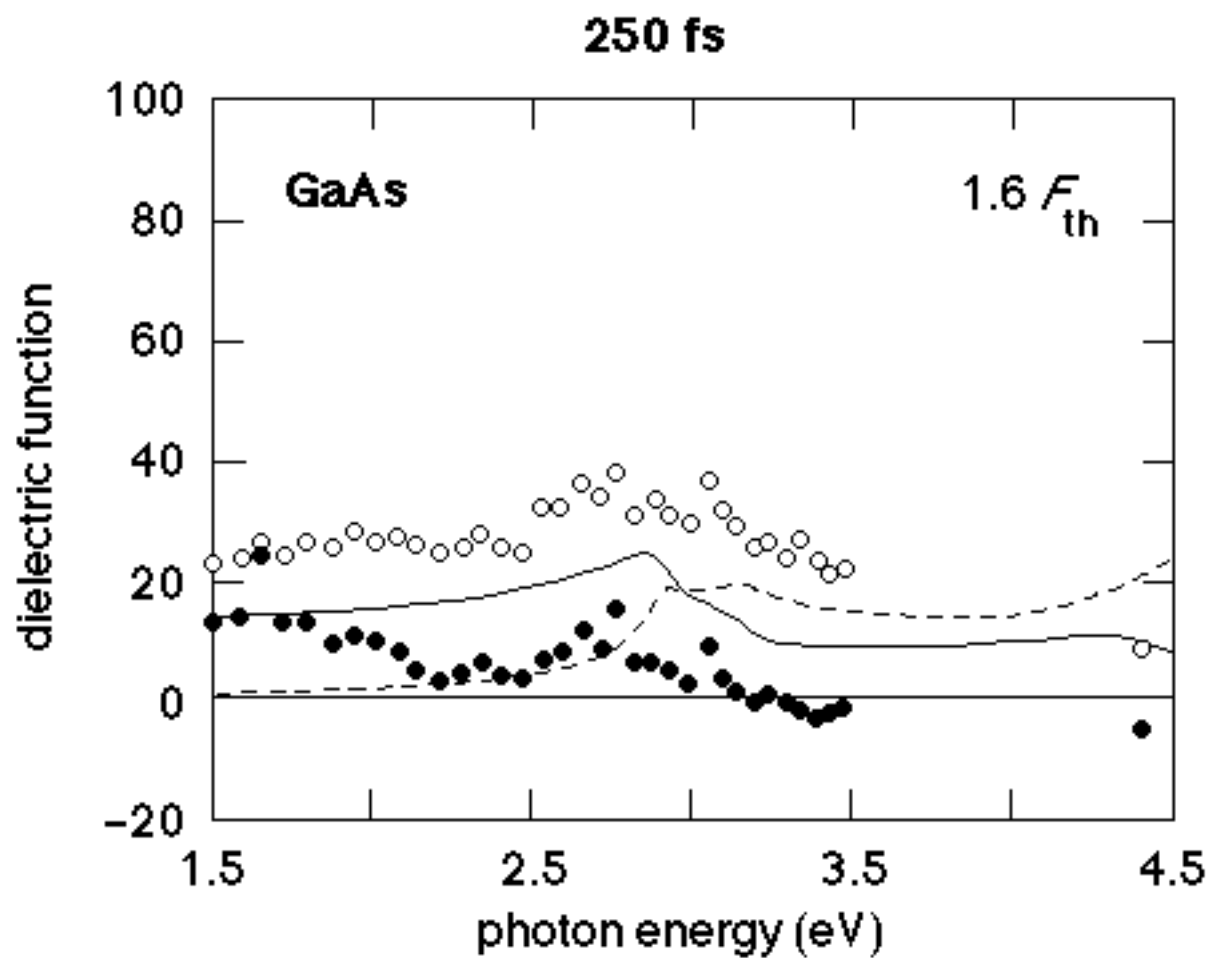
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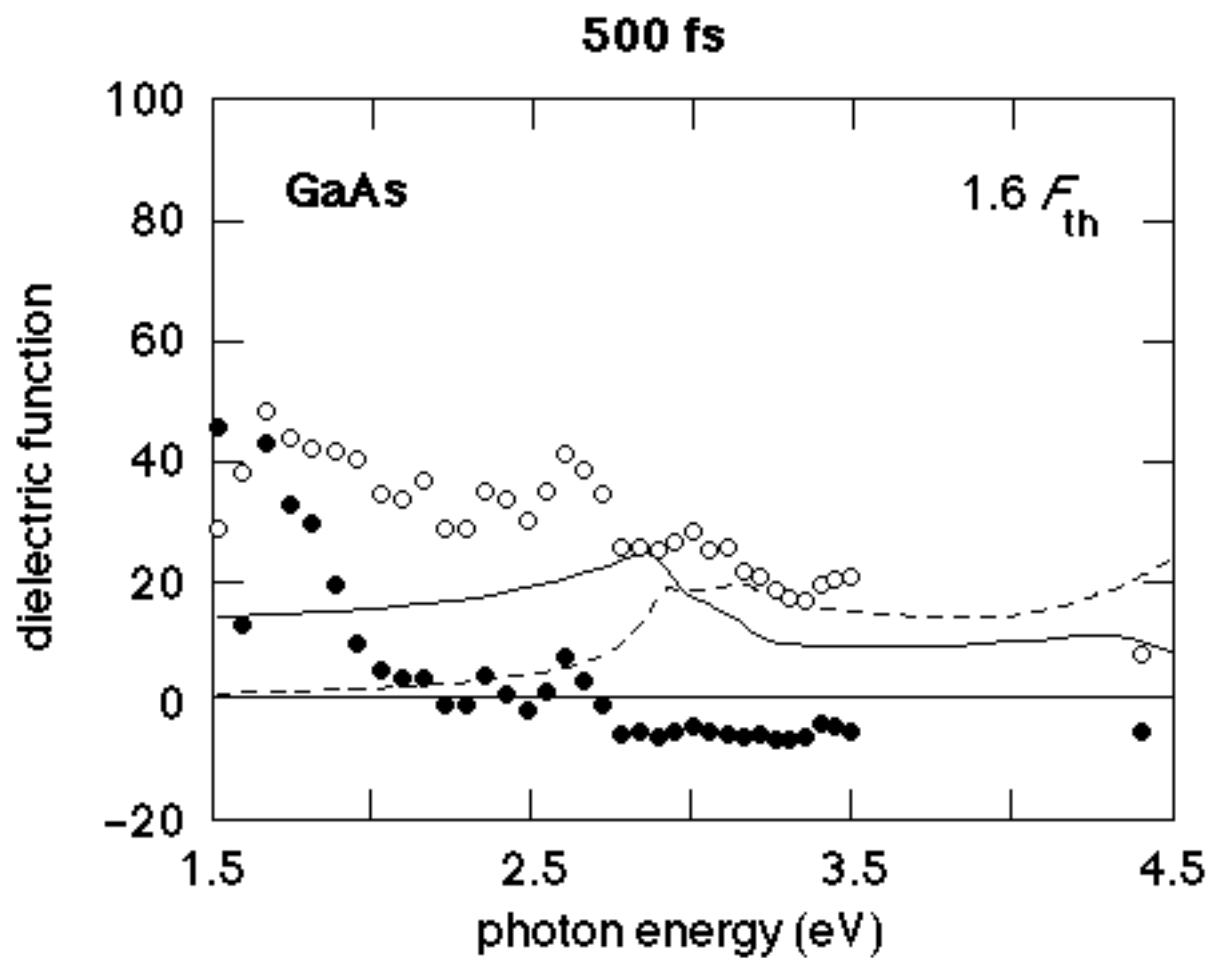
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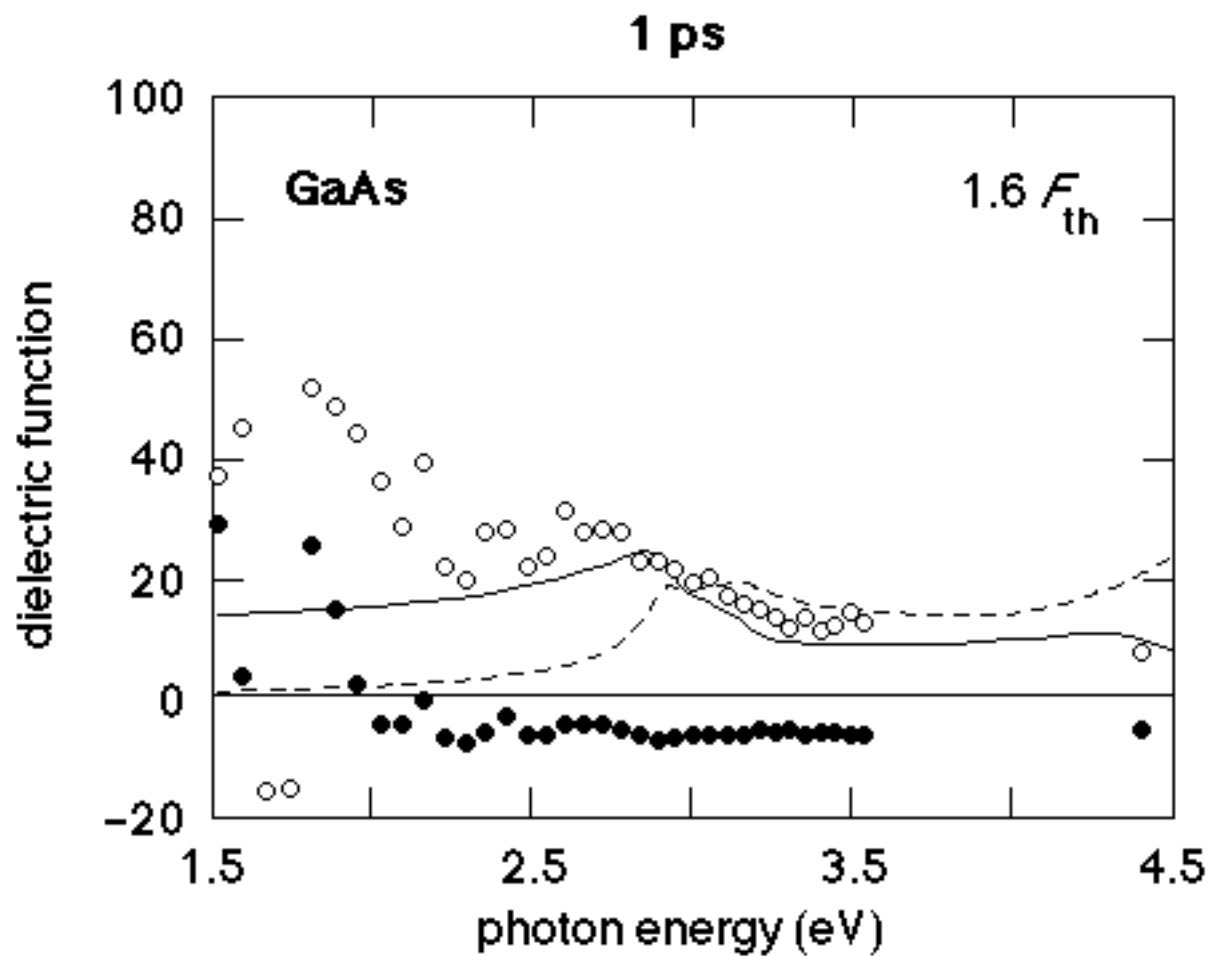
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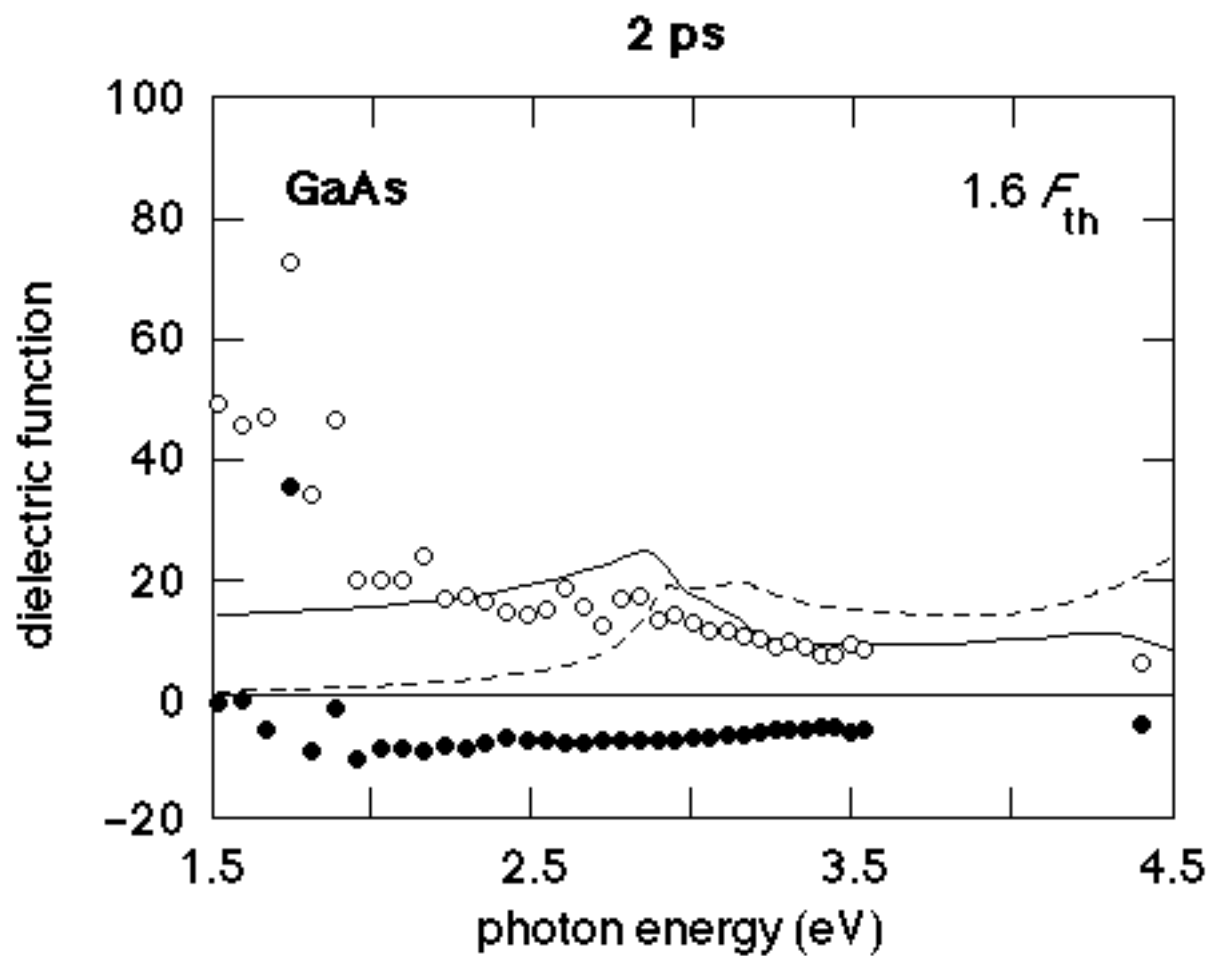
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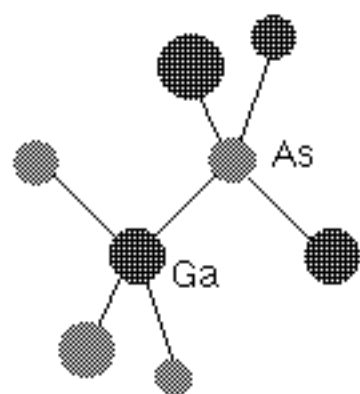


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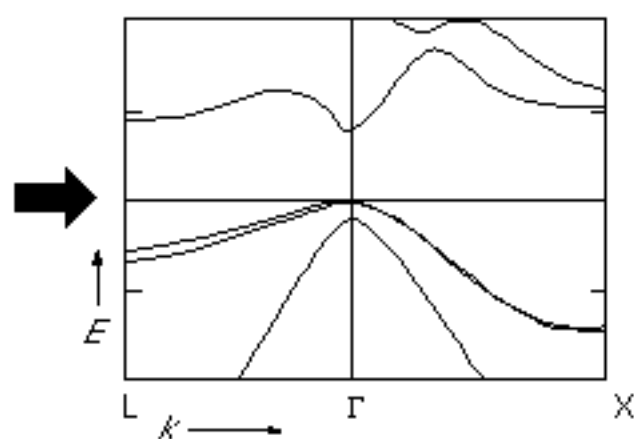


DISCUSSION

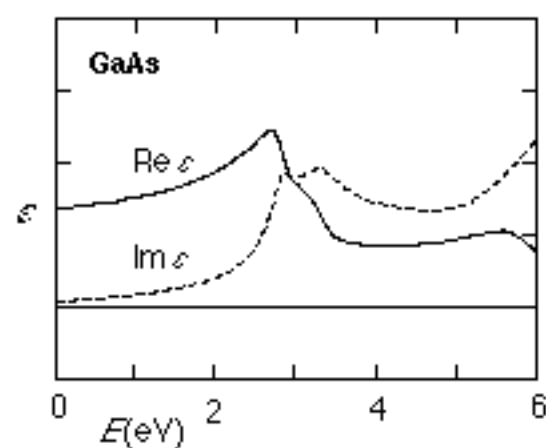
structure



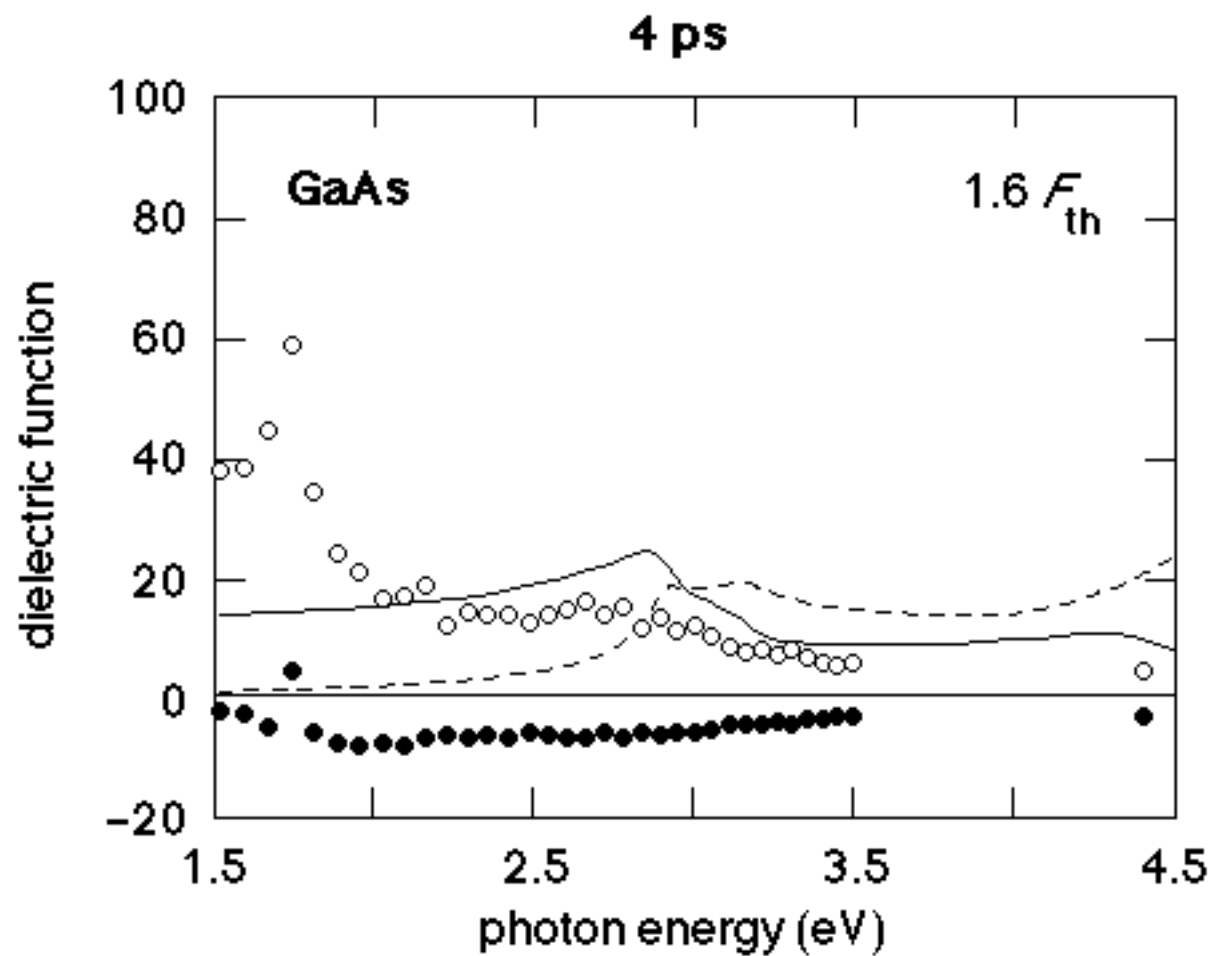
bandstructure



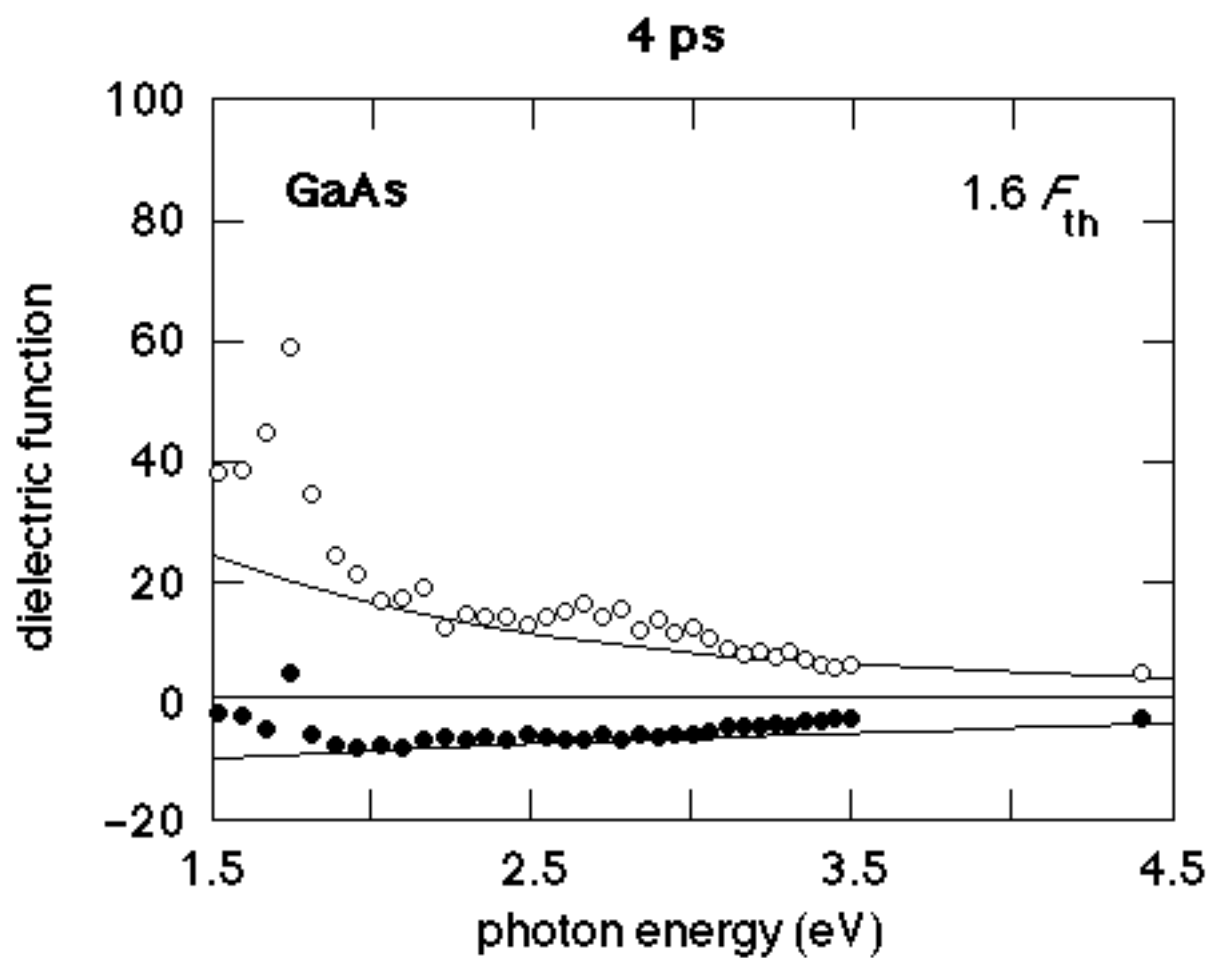
dielectric function



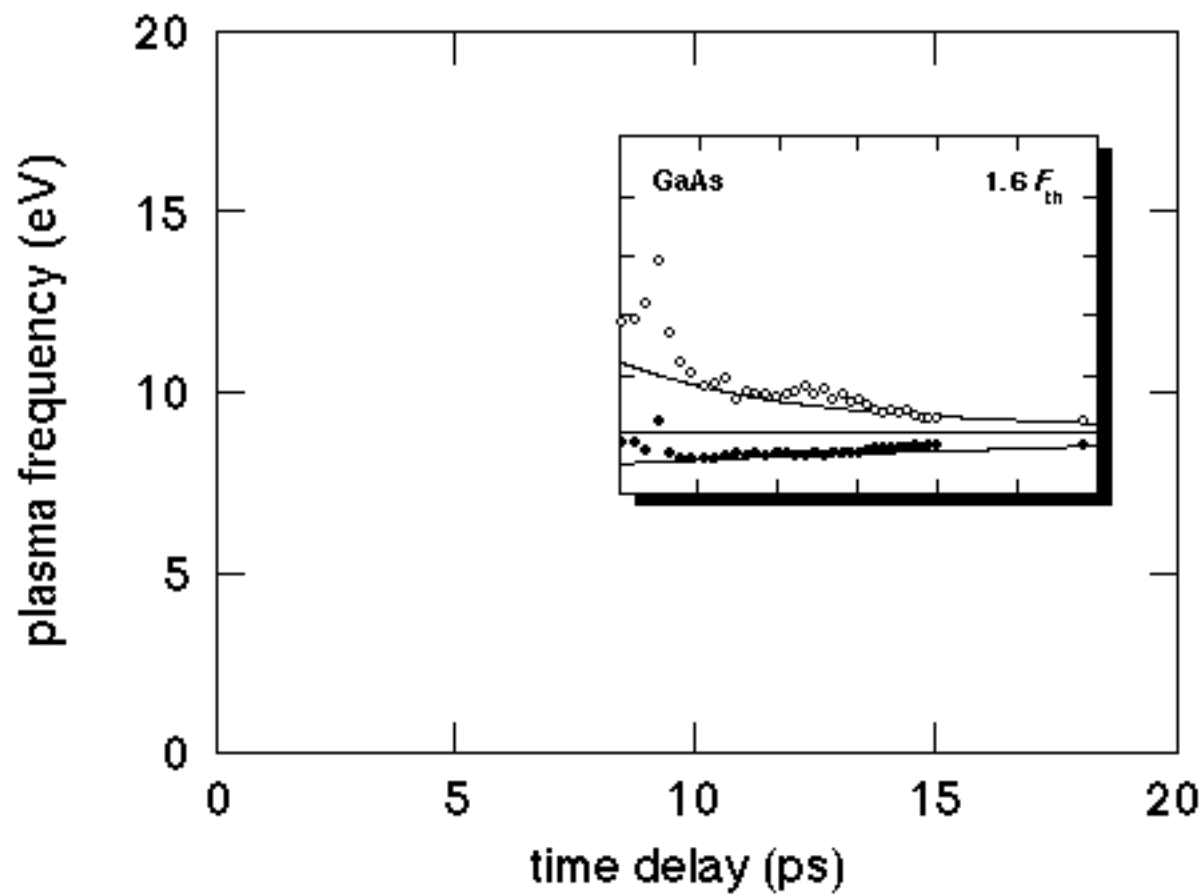
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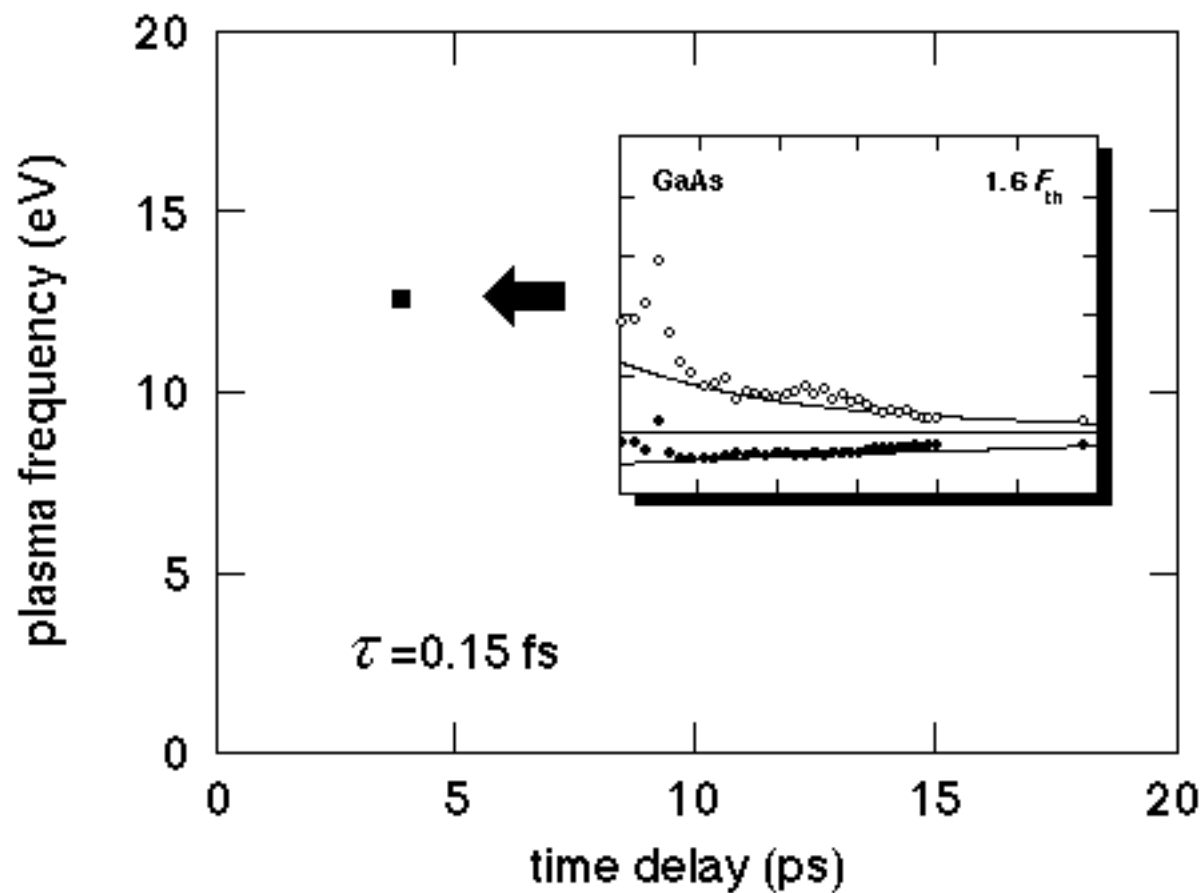
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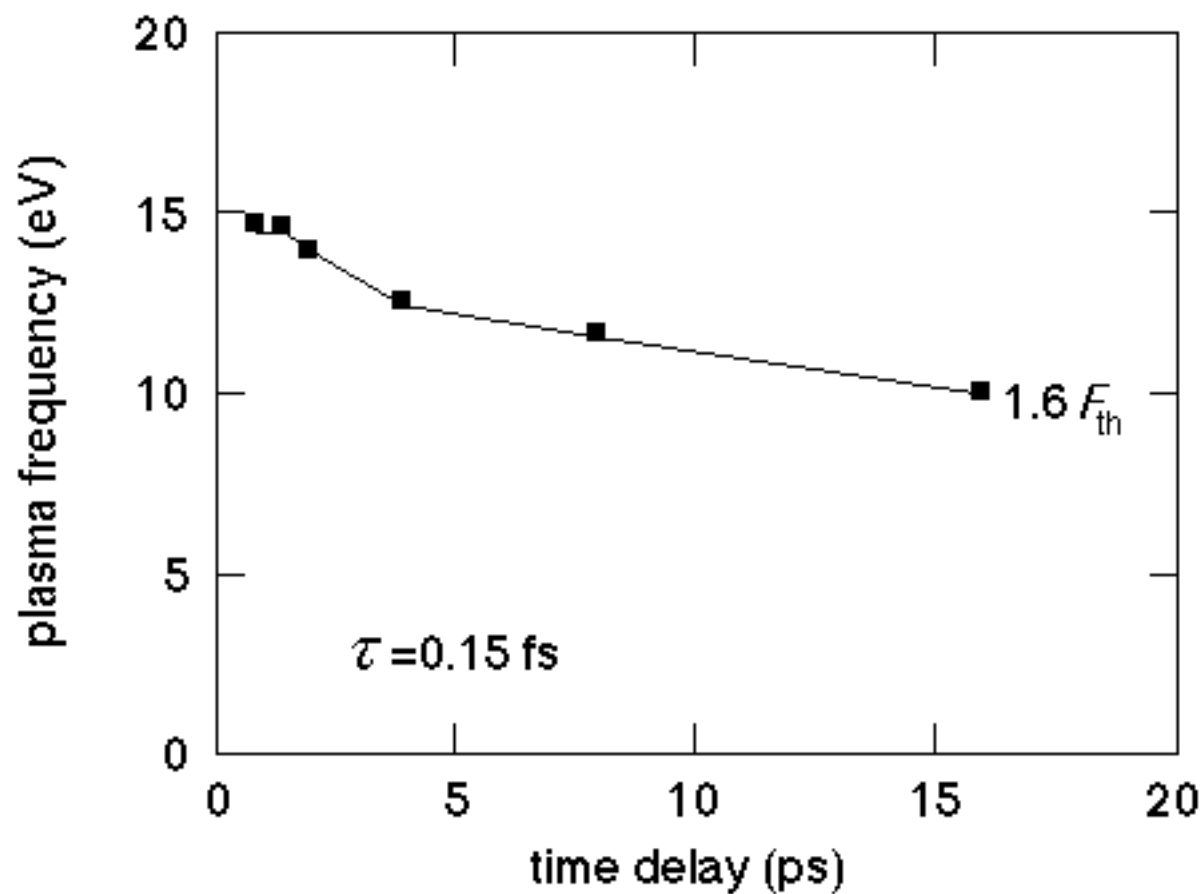
CARRIER DENSITY



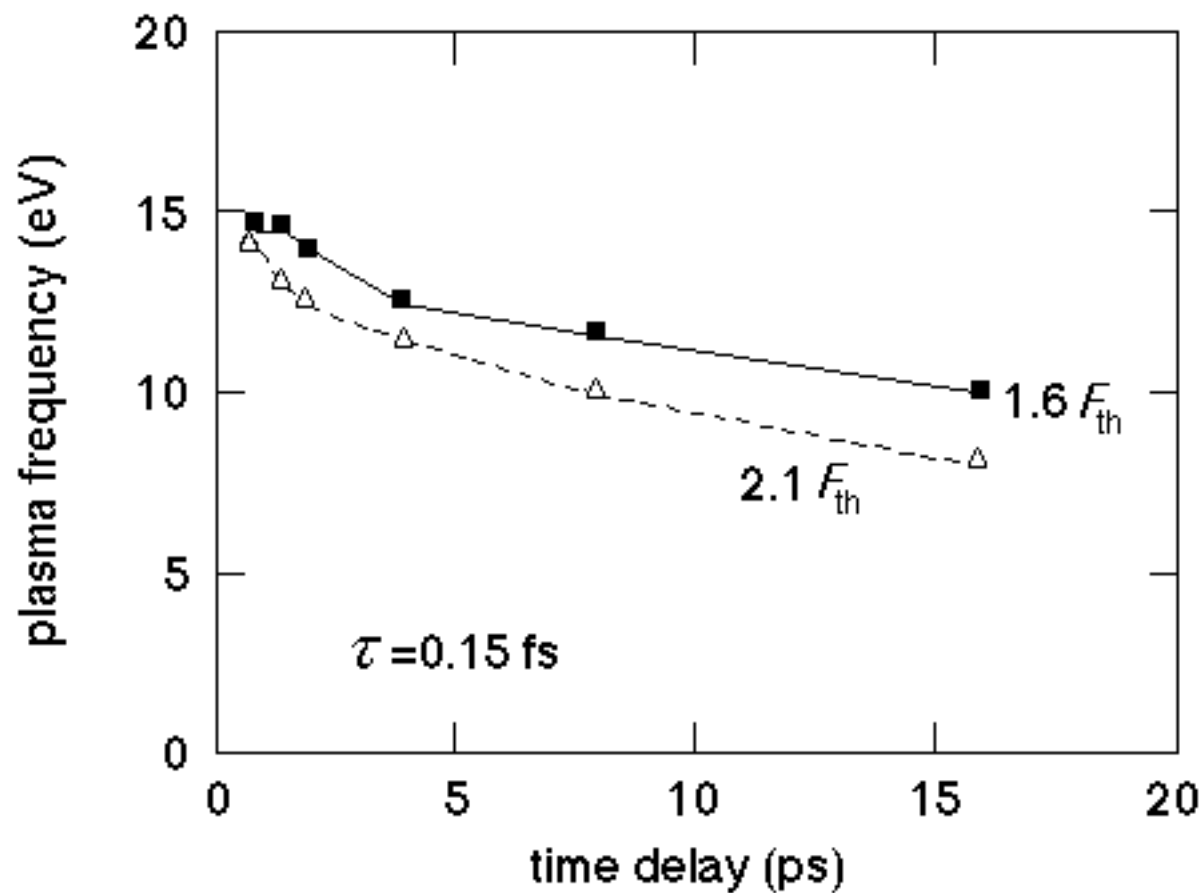
CARRIER DENSITY



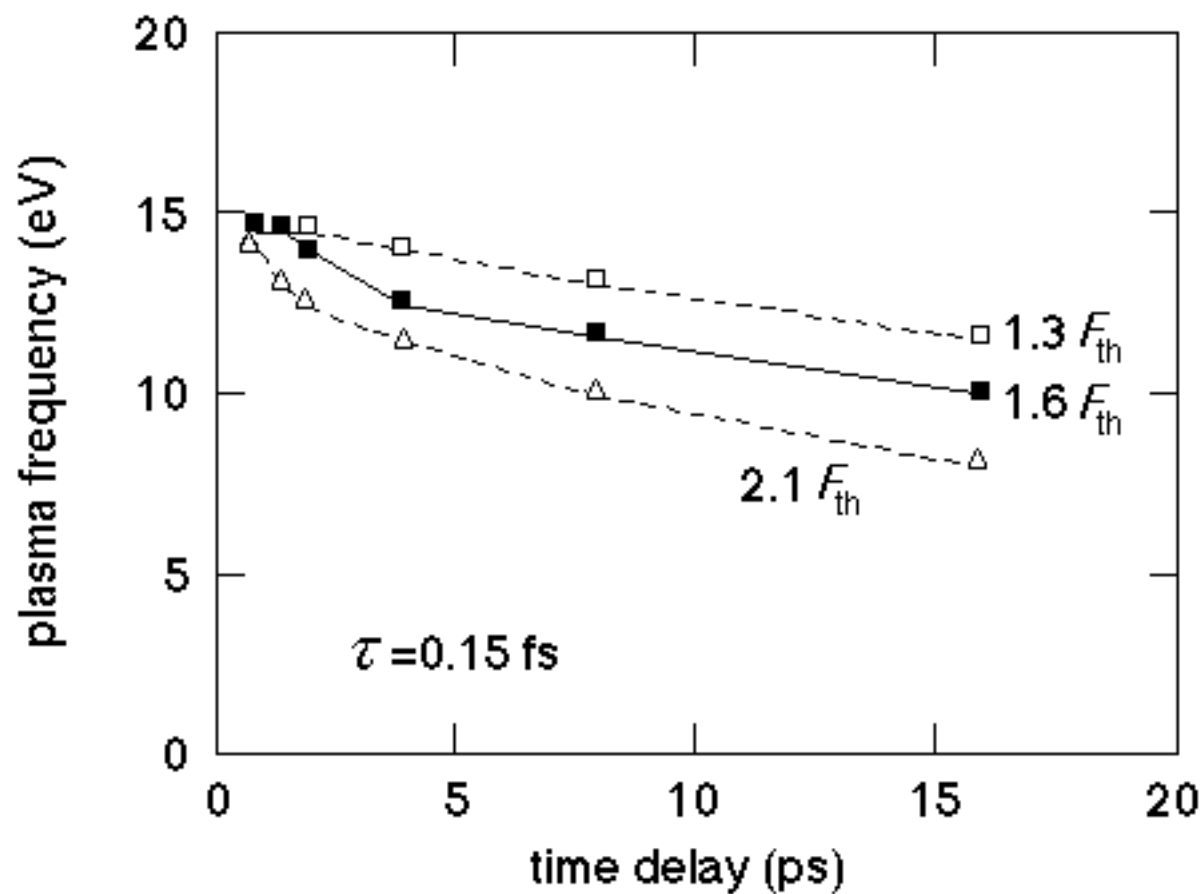
CARRIER DENSITY



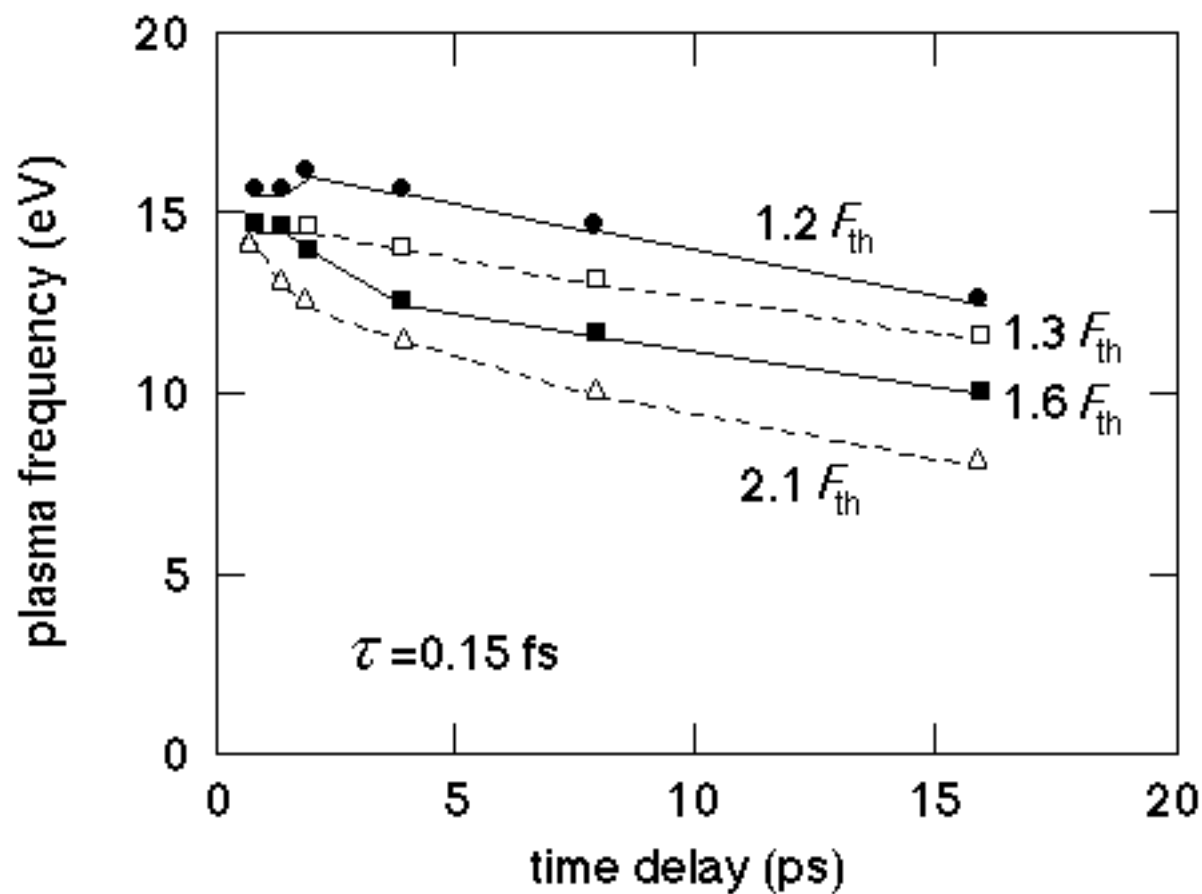
CARRIER DENSITY



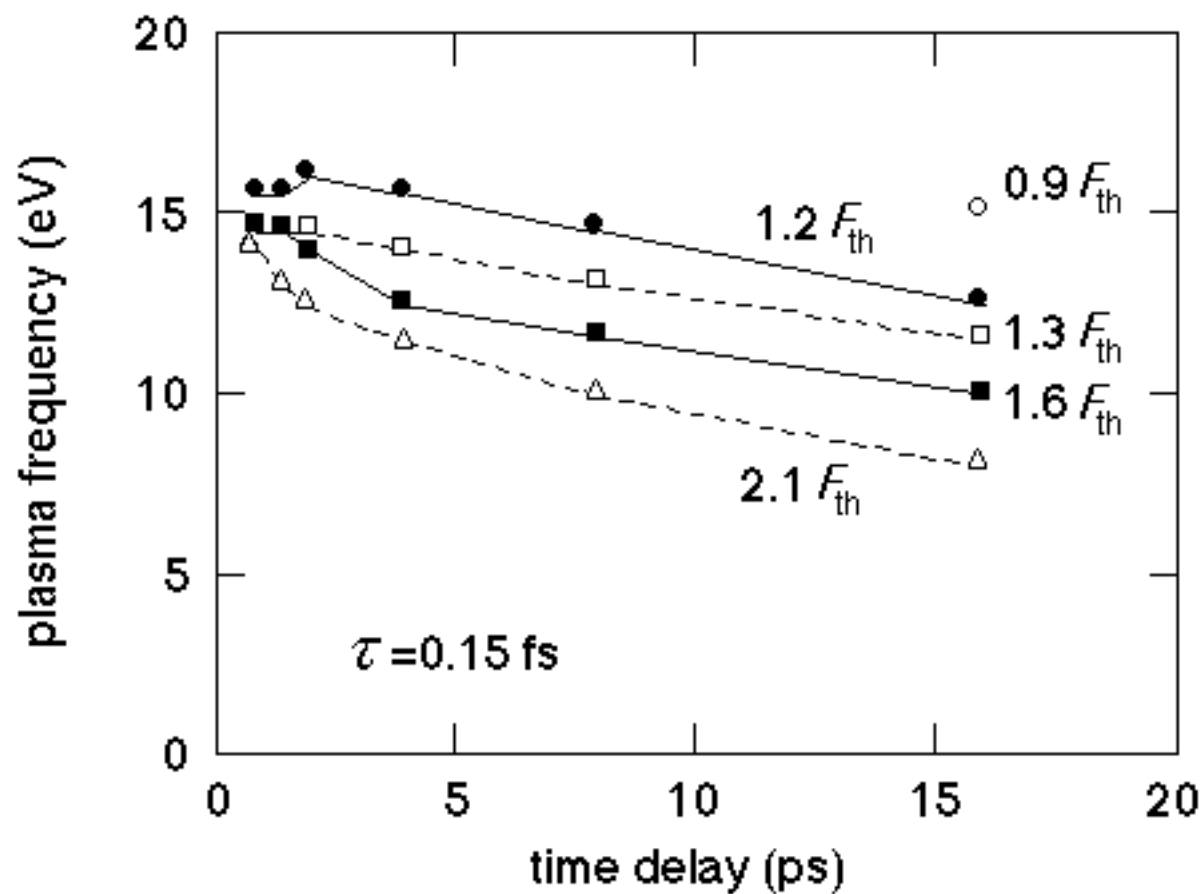
CARRIER DENSITY



CARRIER DENSITY



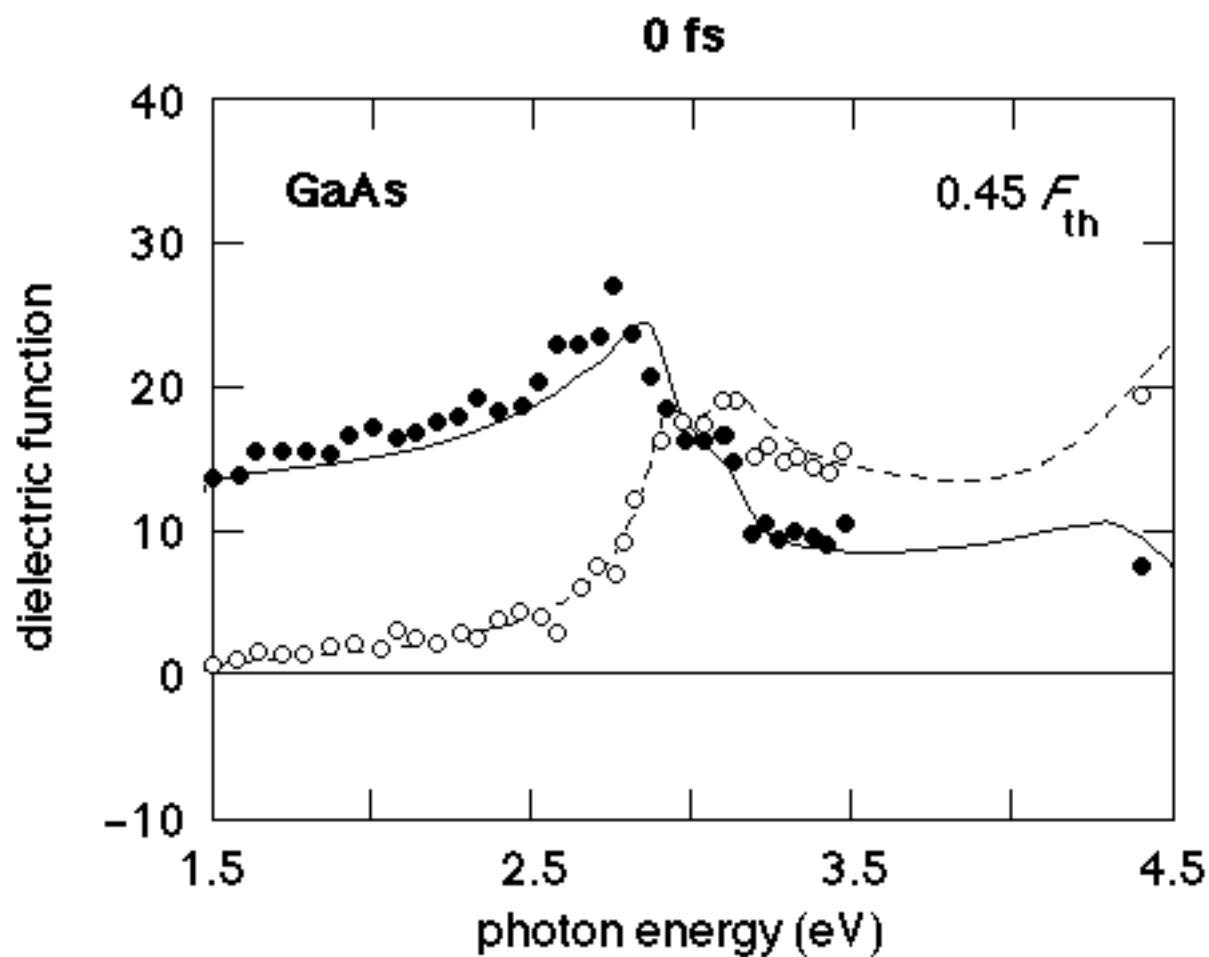
CARRIER DENSITY



- ① Method
- ② Results
- ③ Discussion

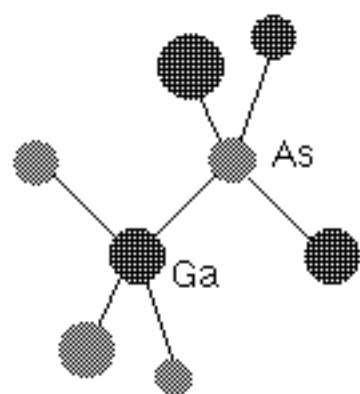


LOW FLUENCE DATA

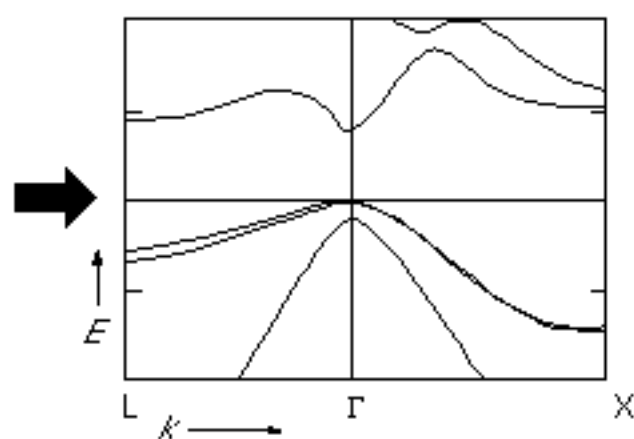


DISCUSSION

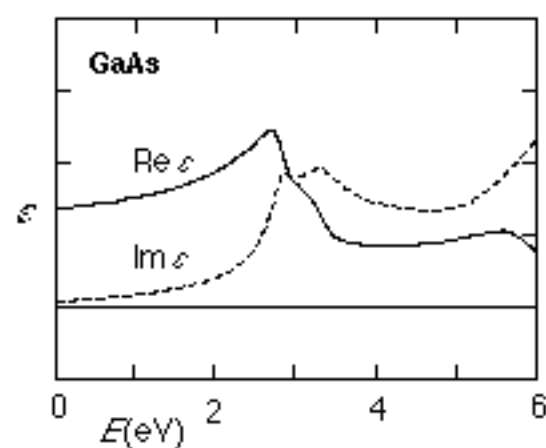
structure



bandstructure

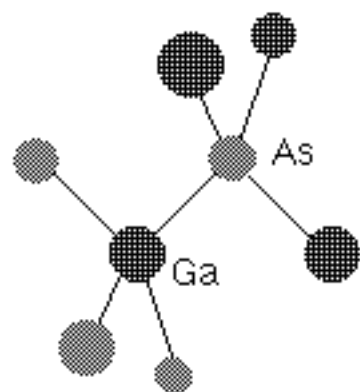


dielectric function

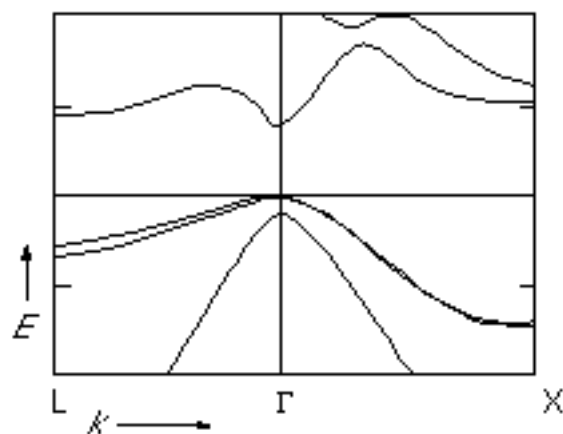


SHORT TIME SCALE (≈ 0.5 ps)

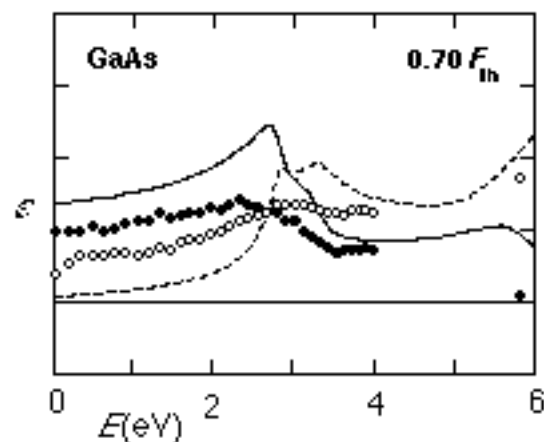
structure



bandstructure

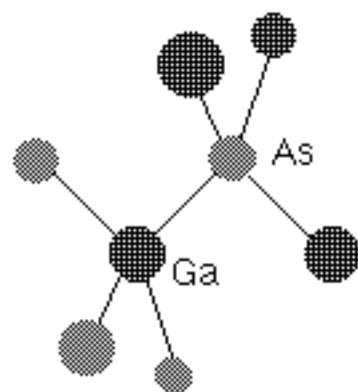


dielectric function

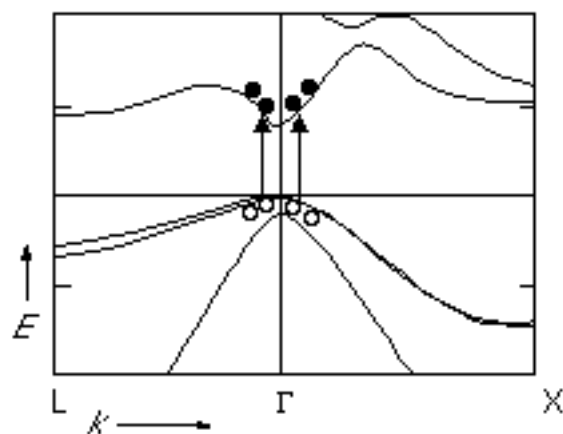


SHORT TIME SCALE (≈ 0.5 ps)

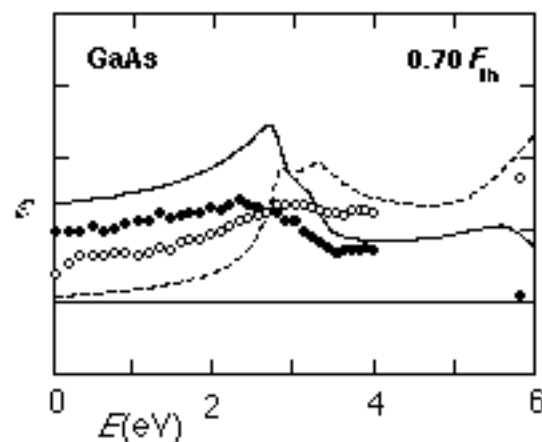
structure



bandstructure

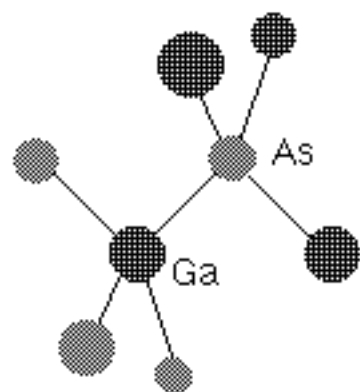


dielectric function

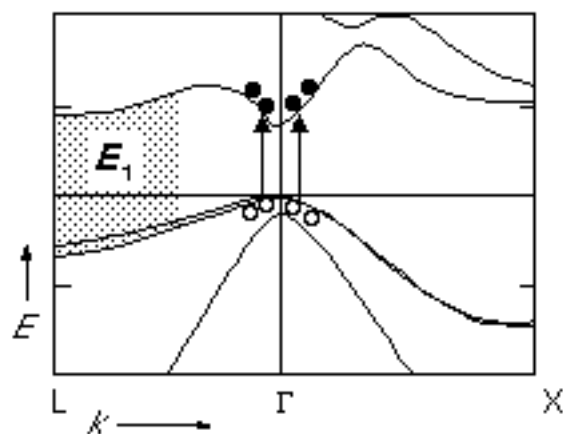


SHORT TIME SCALE (≈ 0.5 ps)

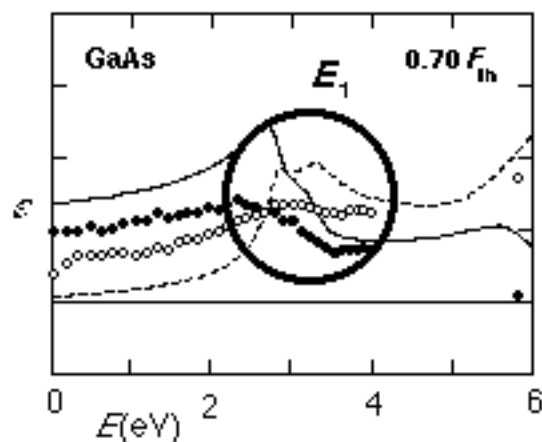
structure



bandstructure

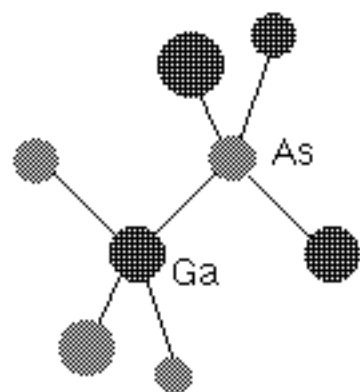


dielectric function

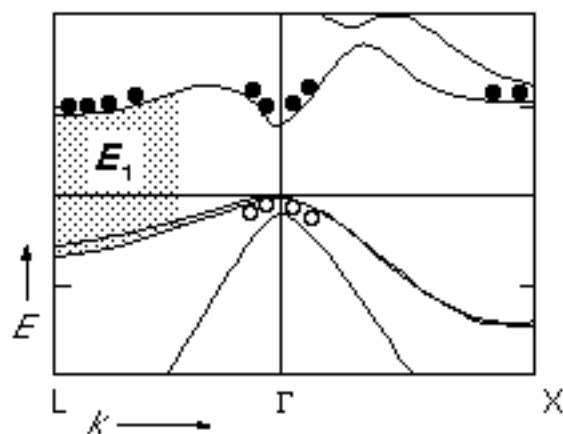


SHORT TIME SCALE (≈ 0.5 ps)

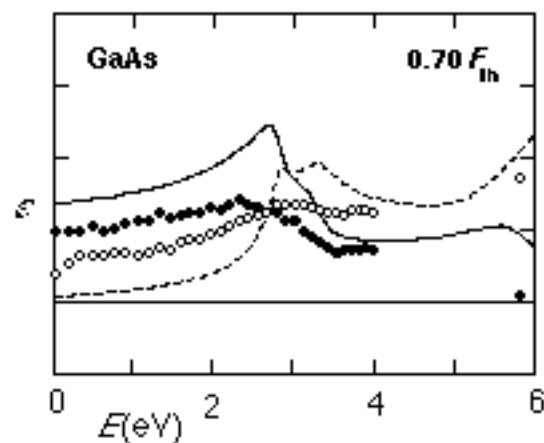
structure



bandstructure

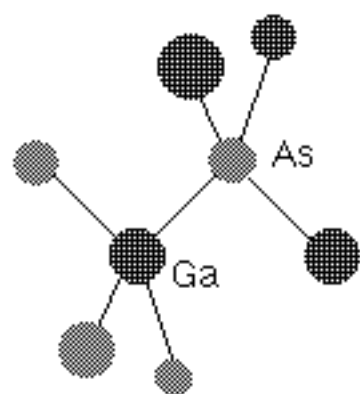


dielectric function

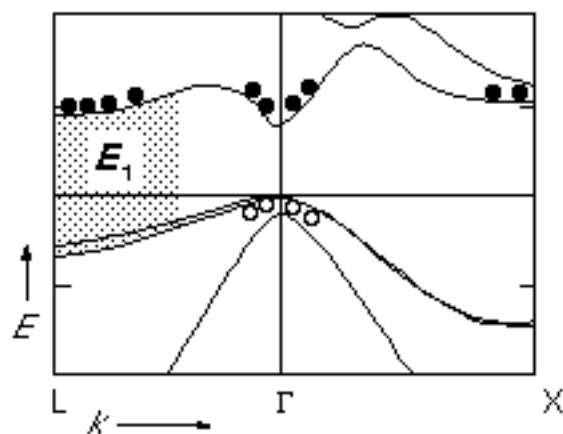


SHORT TIME SCALE (≈ 0.5 ps)

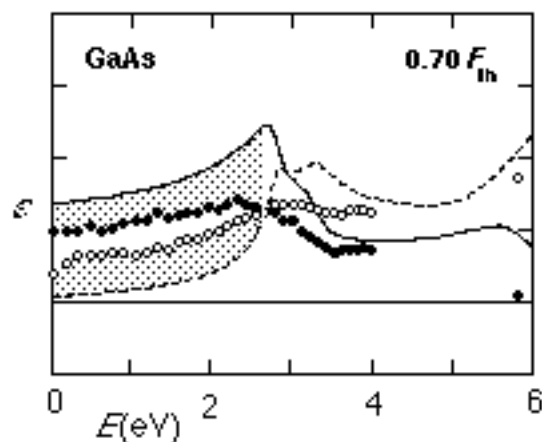
structure



bandstructure

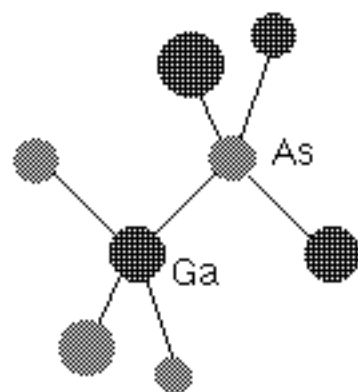


dielectric function

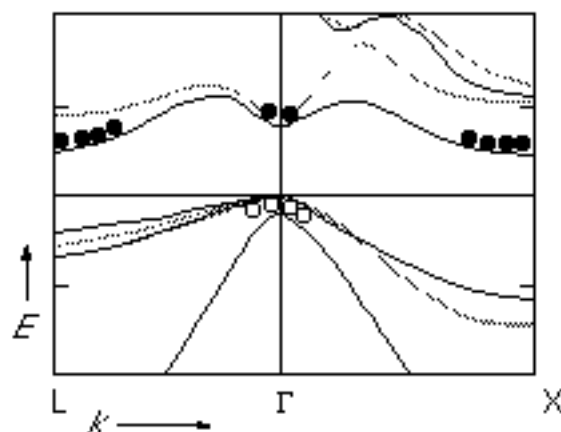


SHORT TIME SCALE (≈ 0.5 ps)

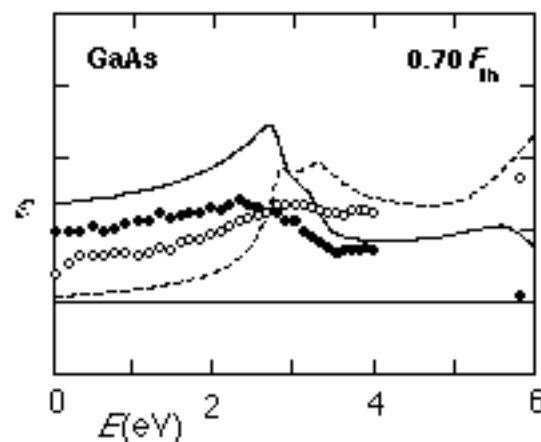
structure



bandstructure



dielectric function



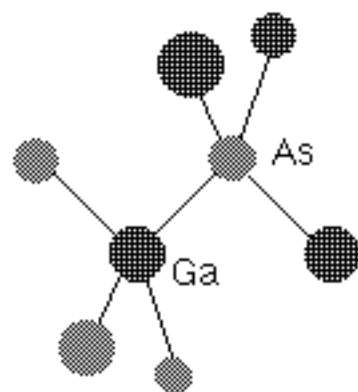
S. Froyen *et al.*, *Phys Rev. B* **28** (1983) 3258

D.H. Kim *et al.*, *Sol. State. Comm.* **89** (1994) 119

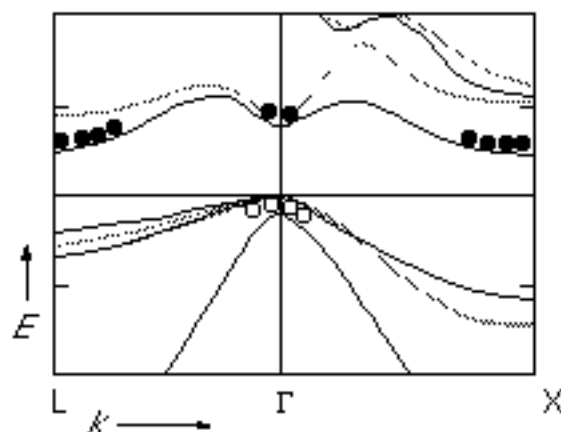


SHORT TIME SCALE (≈ 0.5 ps)

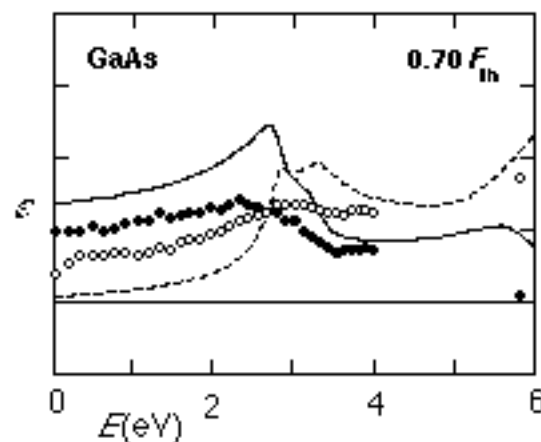
structure



bandstructure



dielectric function

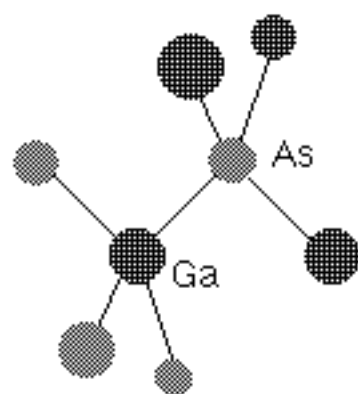


► electronic effects dominate at short time scales...

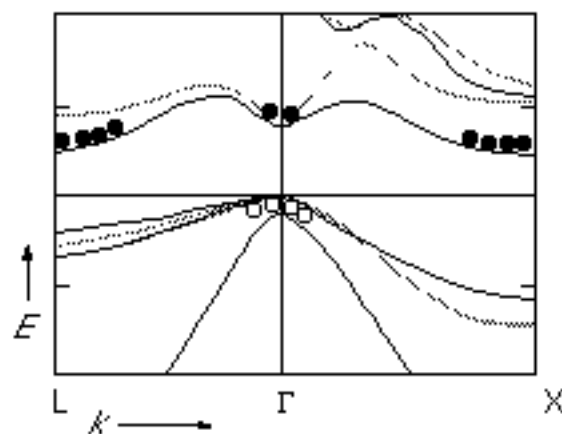


SHORT TIME SCALE (≈ 0.5 ps)

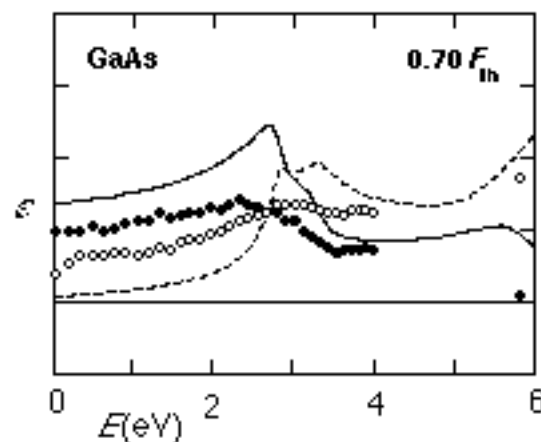
structure



bandstructure



dielectric function

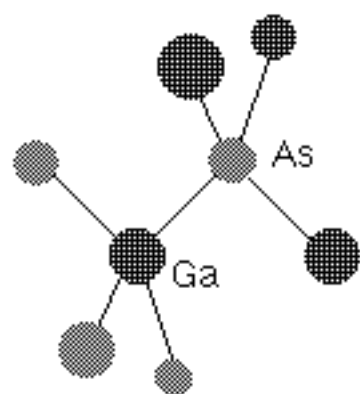


► ...but they are not as simple as we used to think

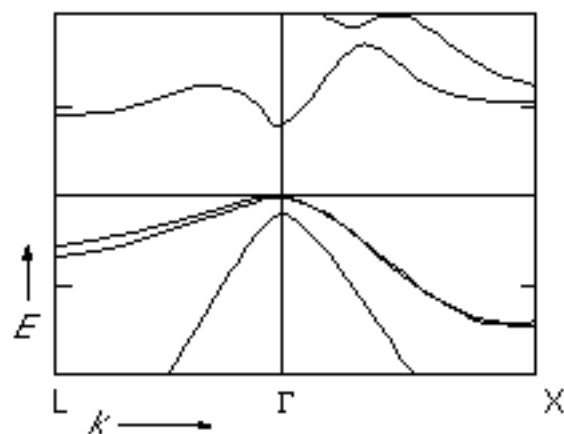


LOW FLUENCE, LONG TIME SCALE

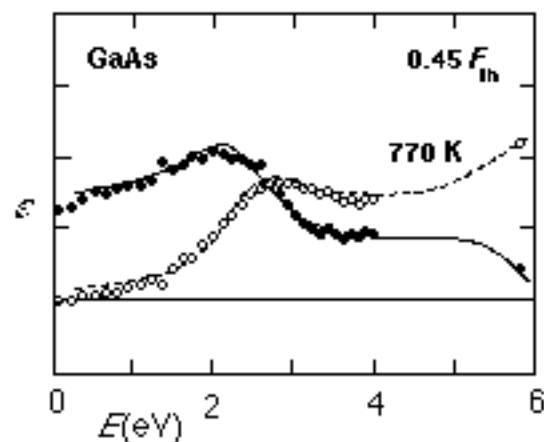
structure



bandstructure

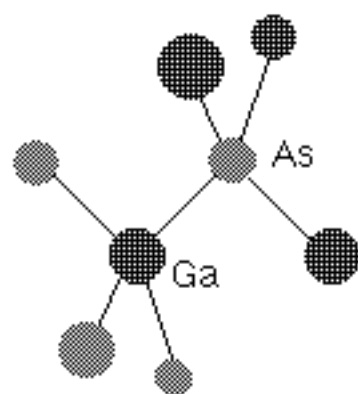


dielectric function

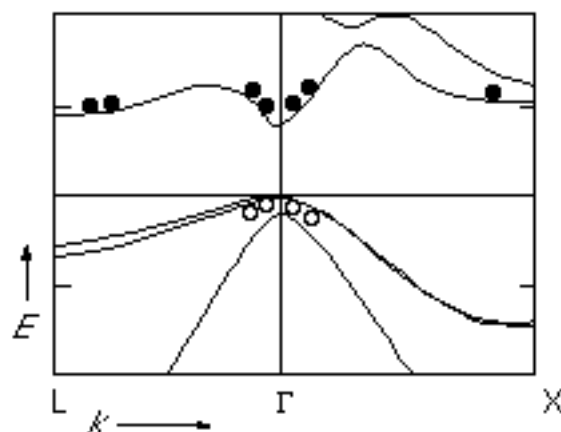


LOW FLUENCE, LONG TIME SCALE

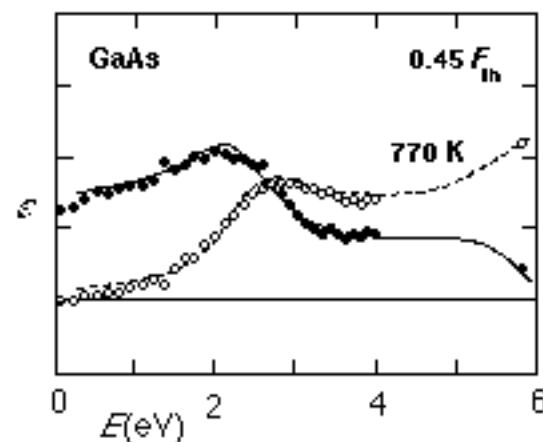
structure



bandstructure



dielectric function

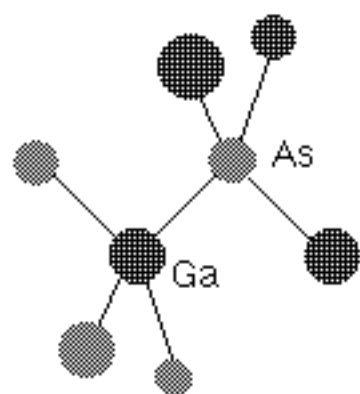


carrier density down, electronic effects subsided...

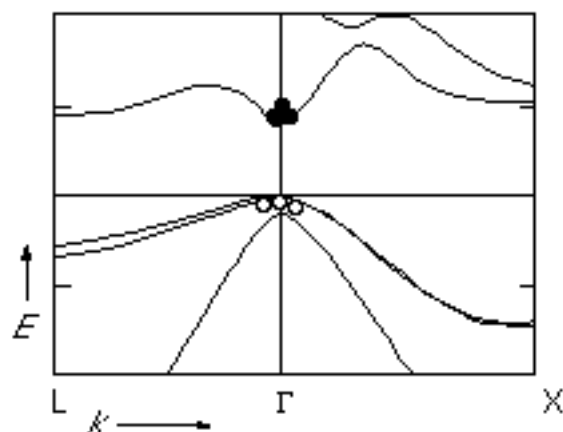


LOW FLUENCE, LONG TIME SCALE

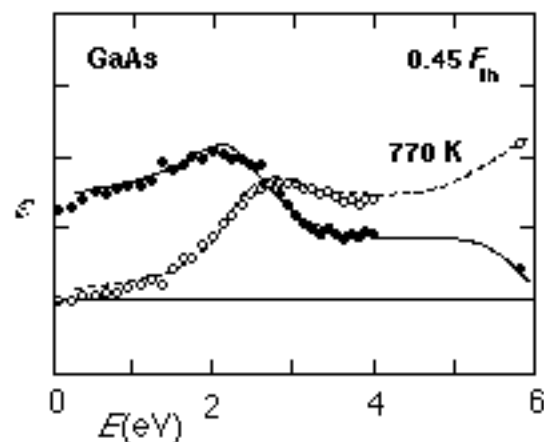
structure



bandstructure



dielectric function

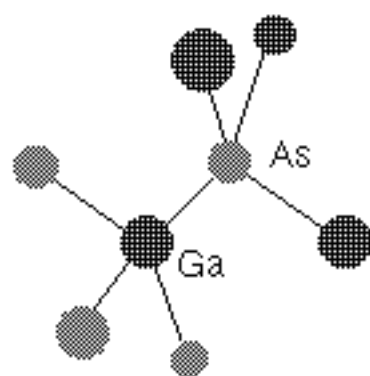


...and lattice heats due to carrier relaxation

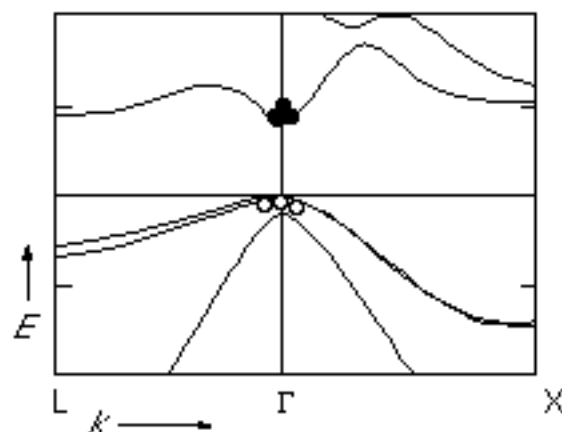


LOW FLUENCE, LONG TIME SCALE

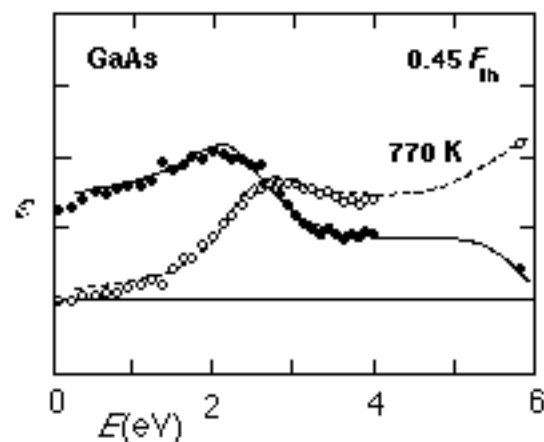
structure



bandstructure



dielectric function

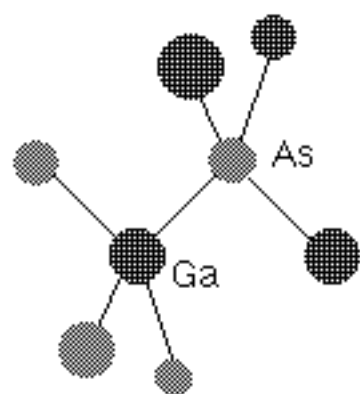


...and lattice heats due to carrier relaxation

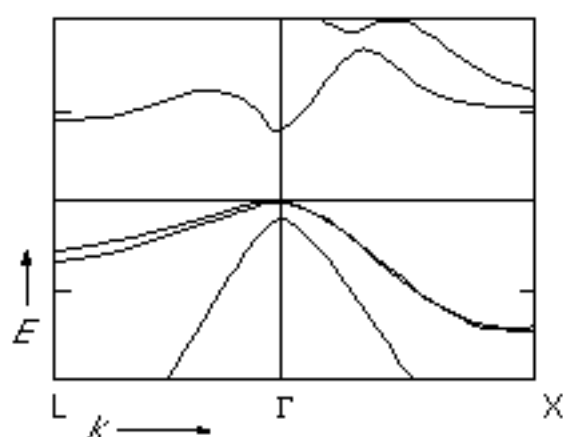


HIGH FLUENCE, LONG TIME SCALE

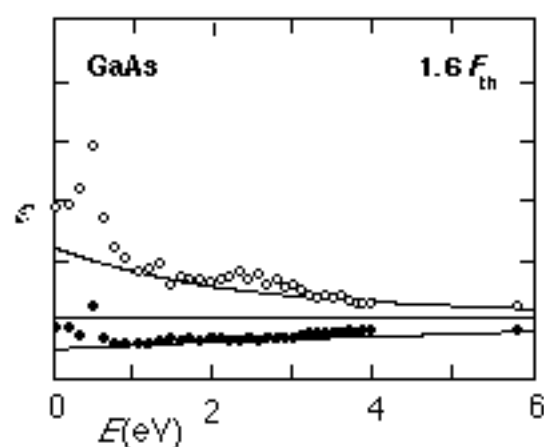
structure



bandstructure



dielectric function

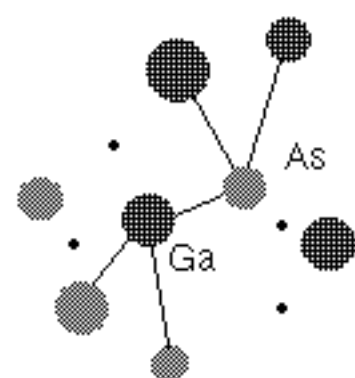


gradual drop in gap \rightarrow not electronic effect

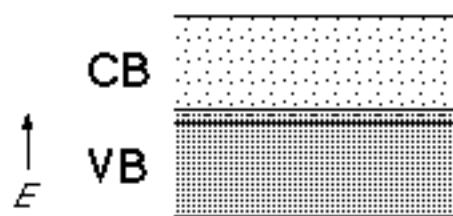


HIGH FLUENCE, LONG TIME SCALE

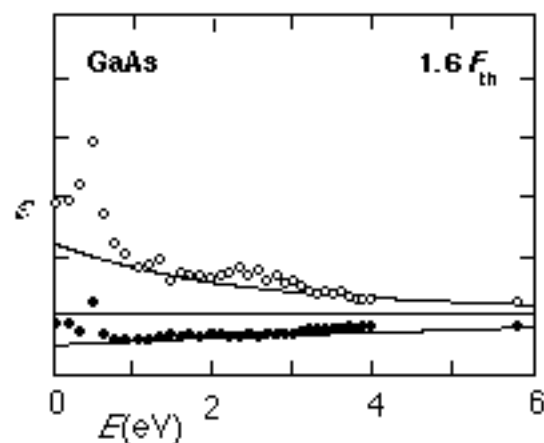
structure



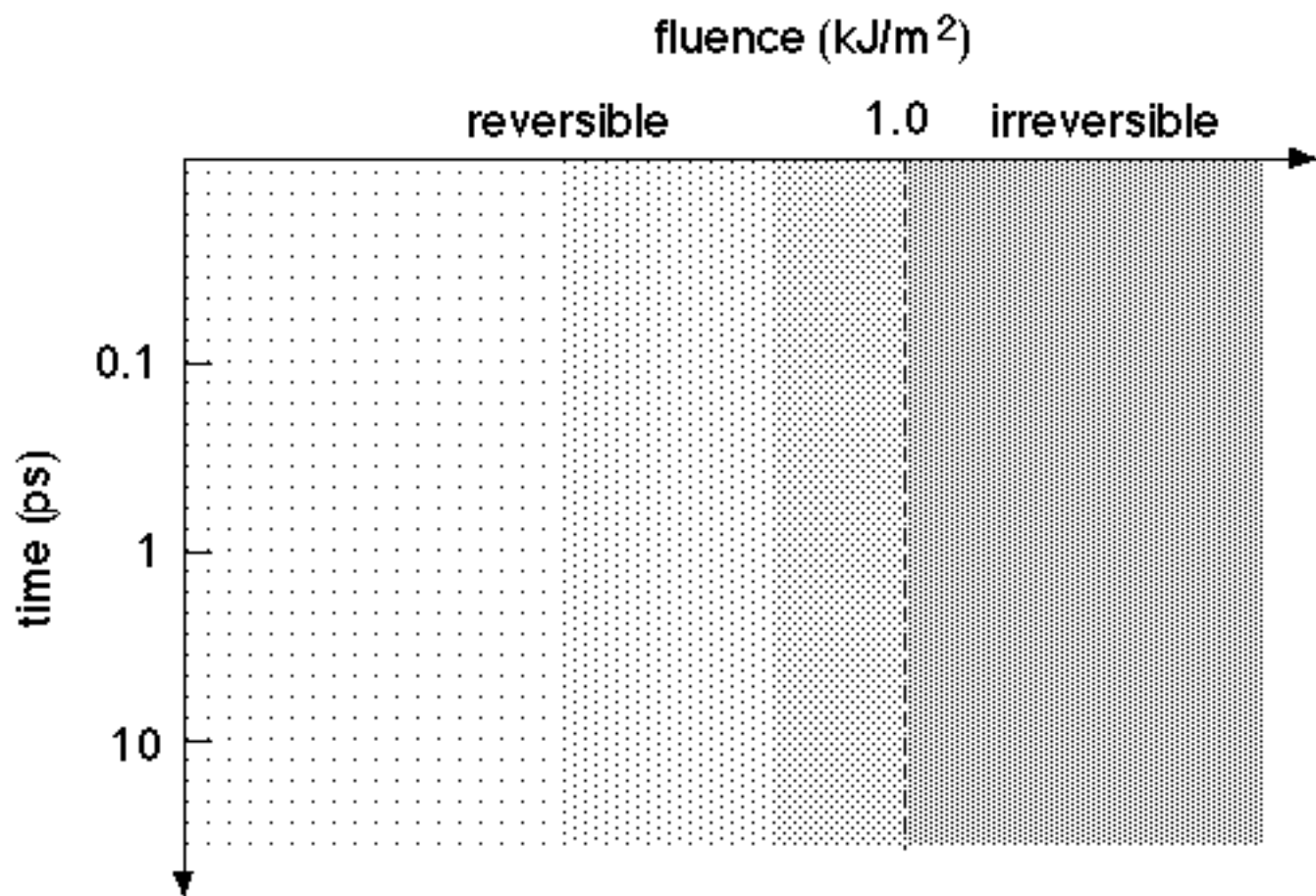
bandstructure



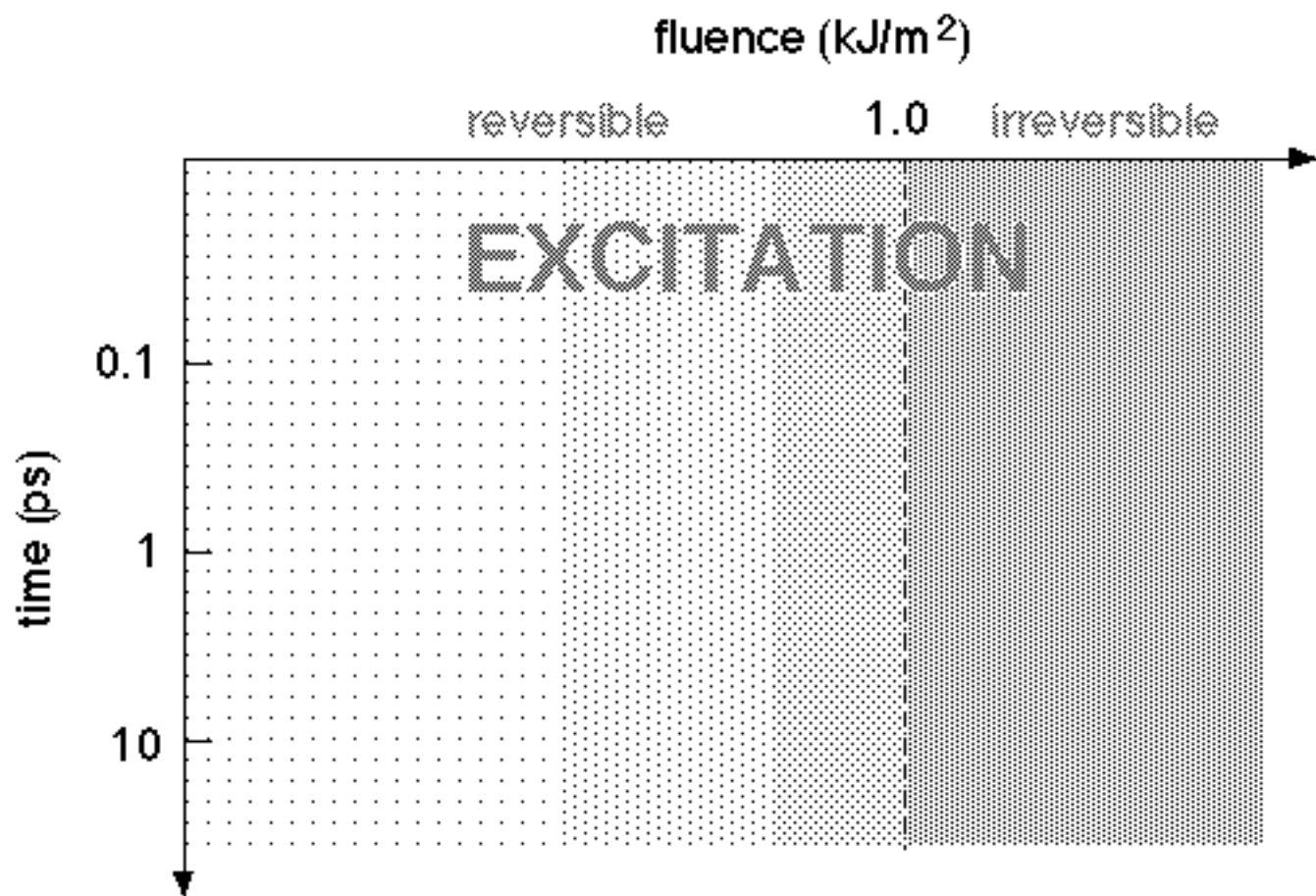
dielectric function



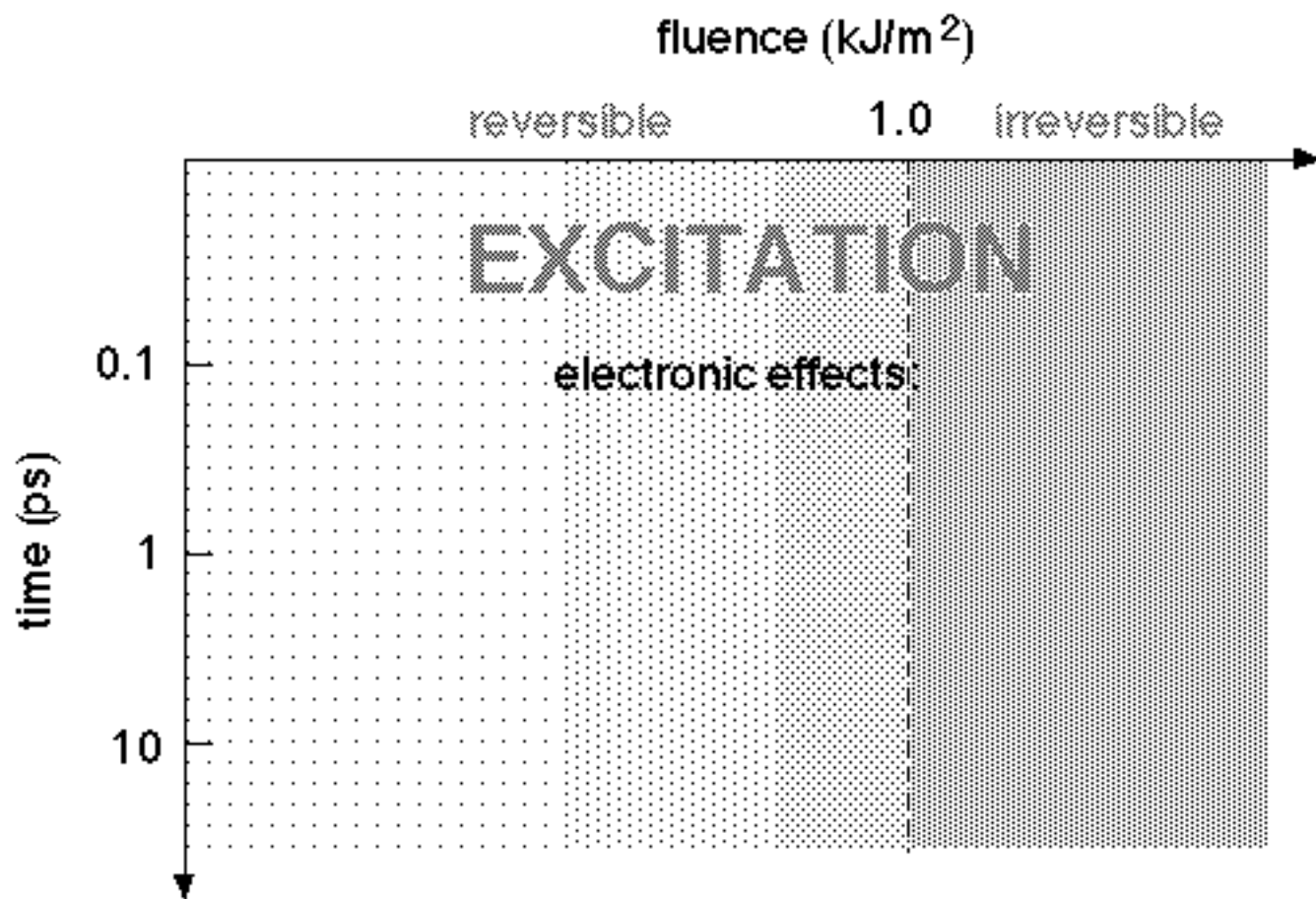
BROADBAND DATA



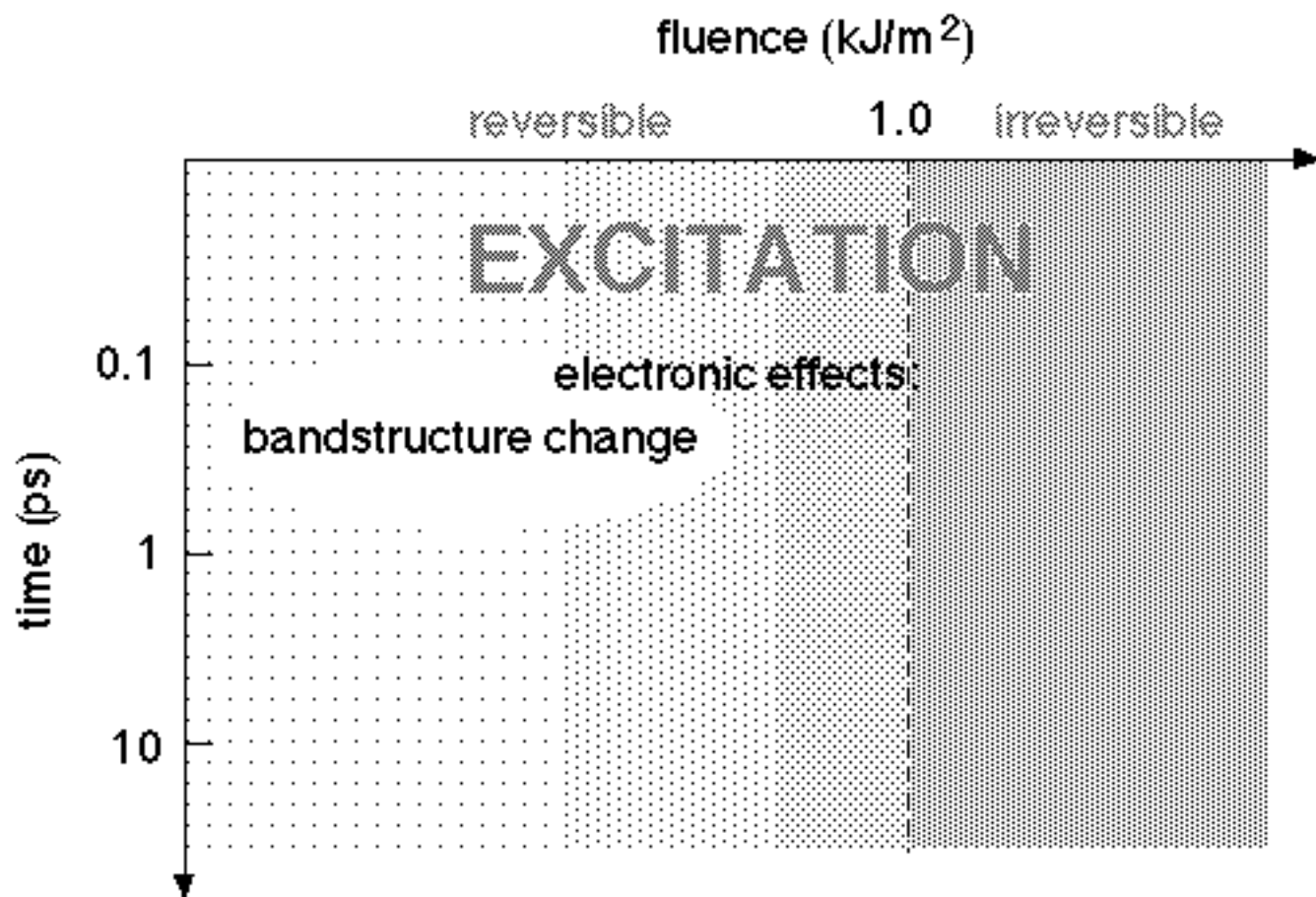
BROADBAND DATA



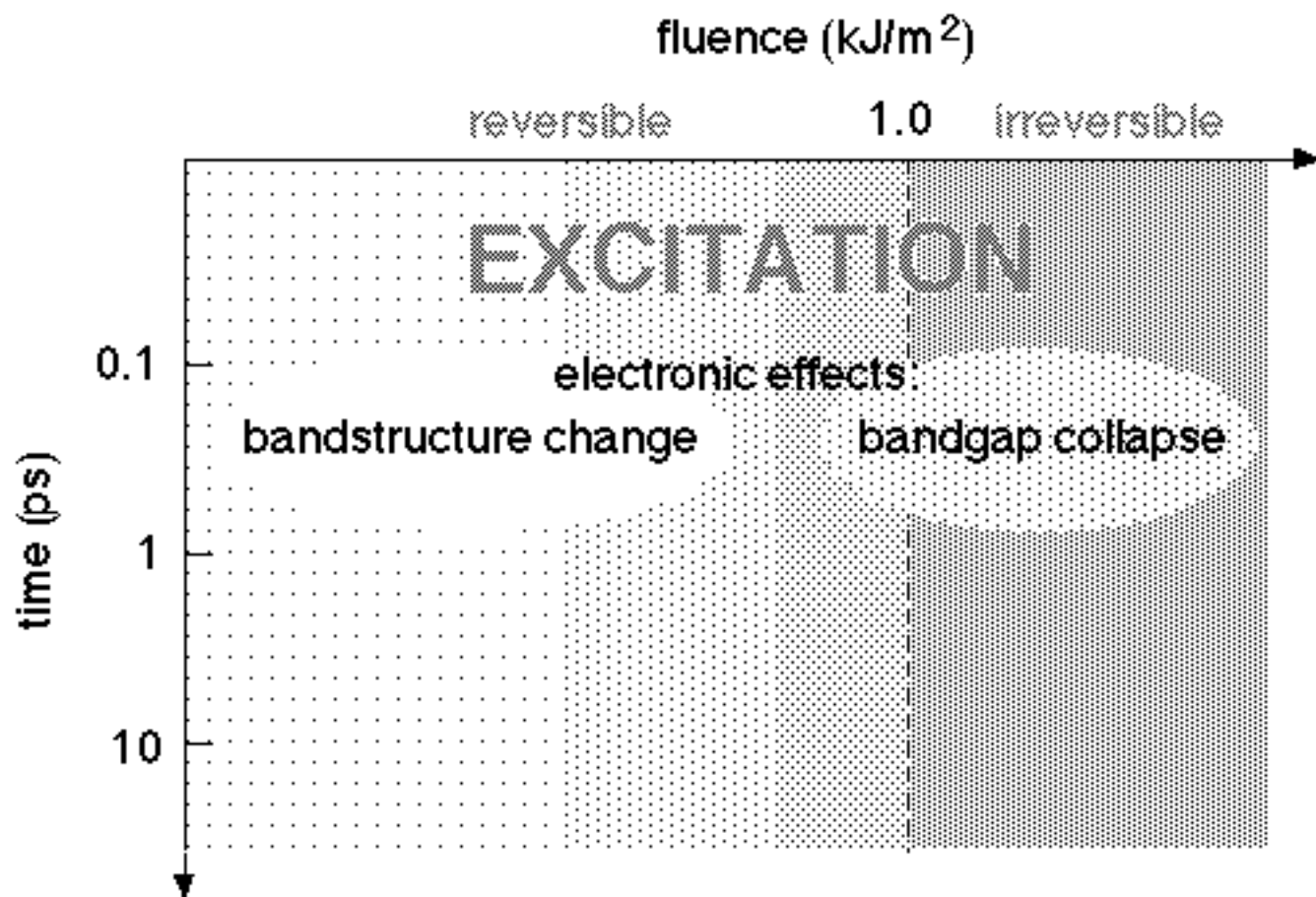
BROADBAND DATA



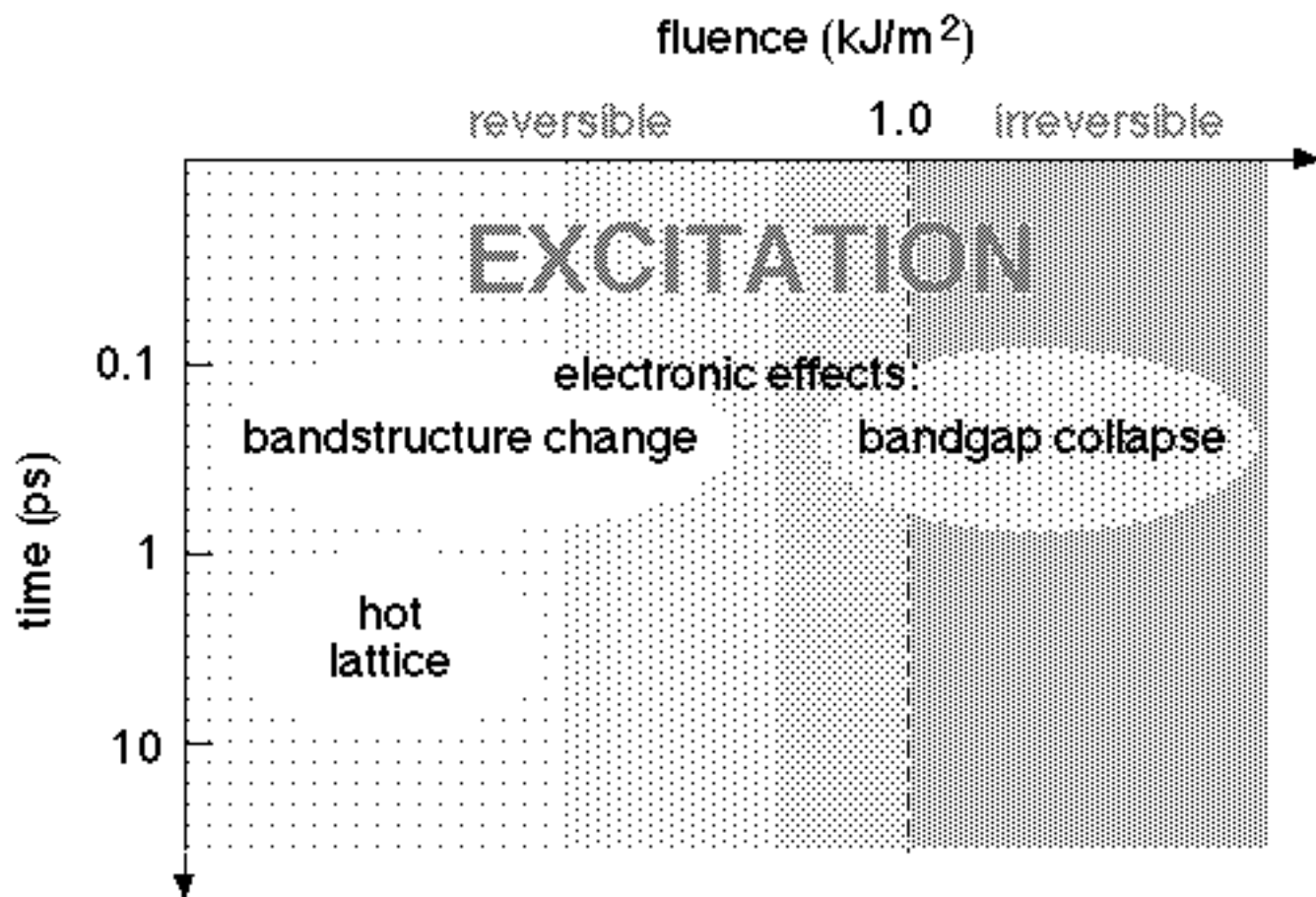
BROADBAND DATA



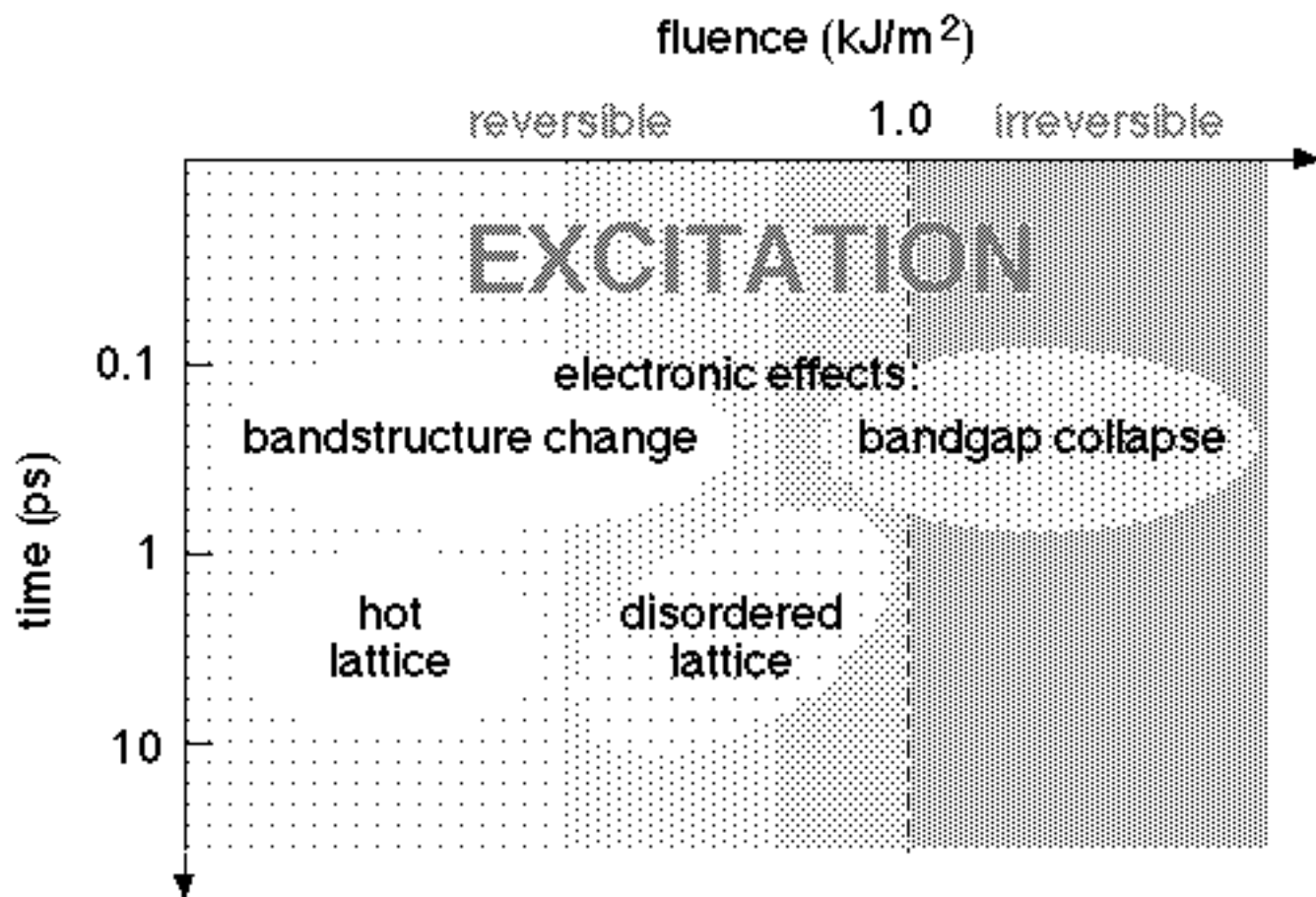
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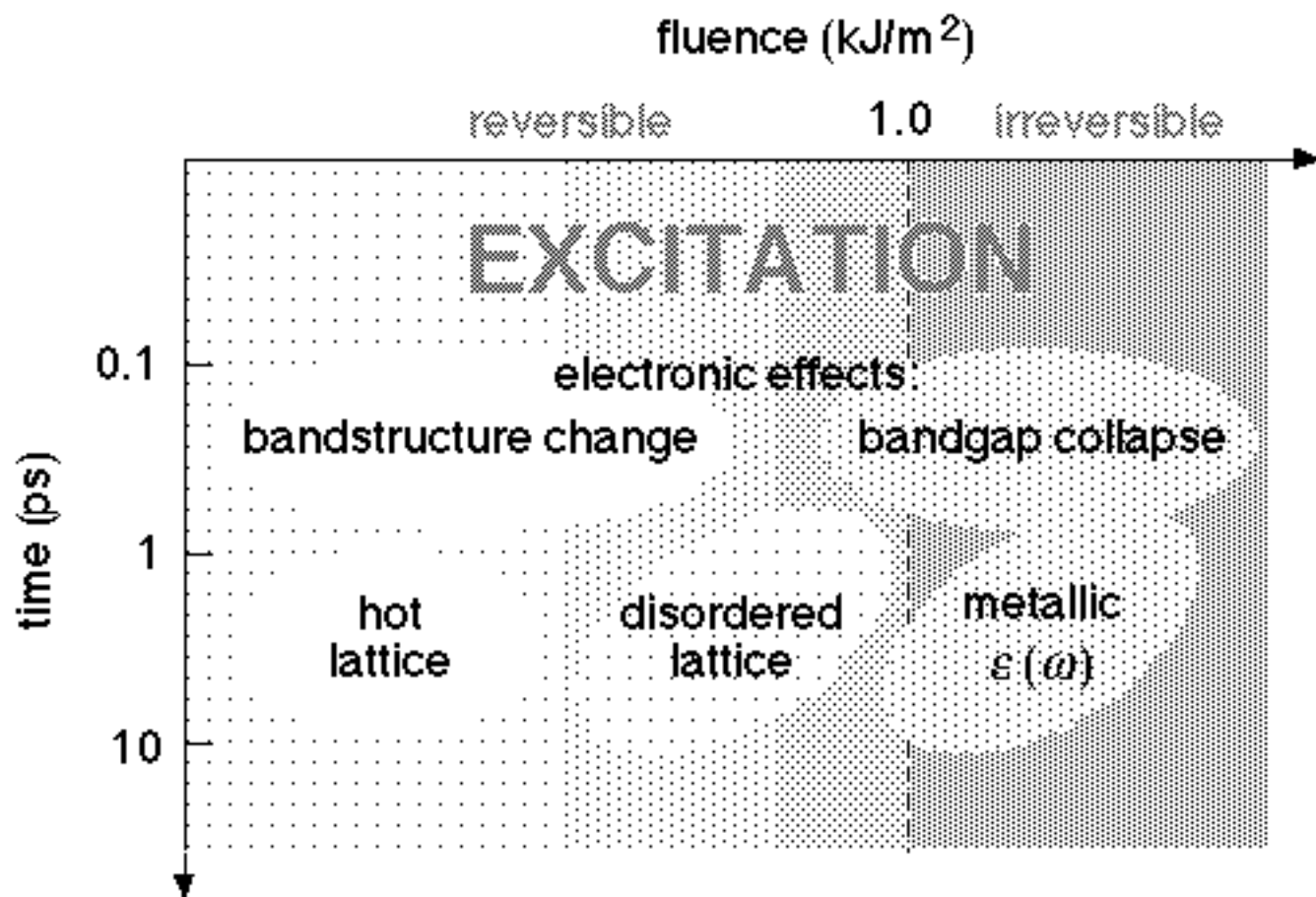
BROADBAND DATA



BROADBAND DATA



BROADBAND DATA



- ▶ measurement of $\epsilon(\omega)$ identifies ultrafast phase changes
- ▶ initial response is electronic, via band structure and electron occupation changes
- ▶ structural effects dominate after a few ps
- ▶ interesting reversible regime

- ▶ strong electronic excitation can drive a structural transition
- ▶ femtosecond lasers allow us to see the dynamics of the transition



Prof. Bloembergen
Prof. Ehrenreich
Prof. Kaxiras
Prof. Klingshirn

ONR, NSF

<http://mazur-www.harvard.edu>

