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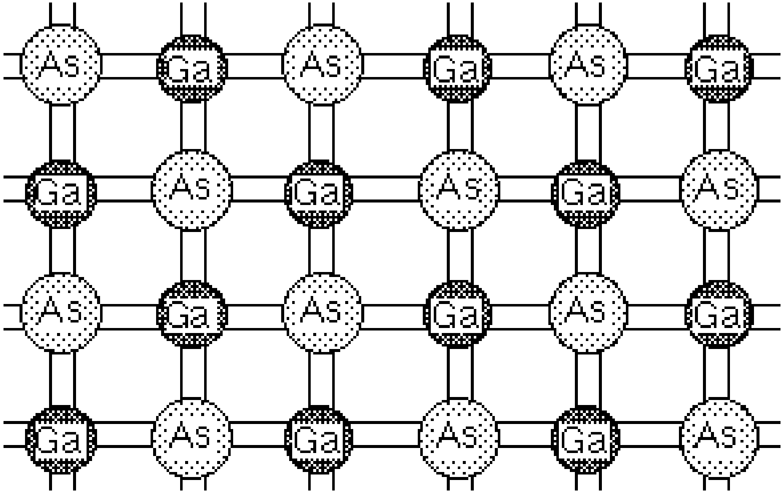
QUICK AS A FLASH: OBSERVING ULTRAFAST LASER-INDUCED DYNAMICS IN SEMICONDUCTORS

Eric Mazur
Paul Callan
Albert Kim
Li Huang
Eli Glezer

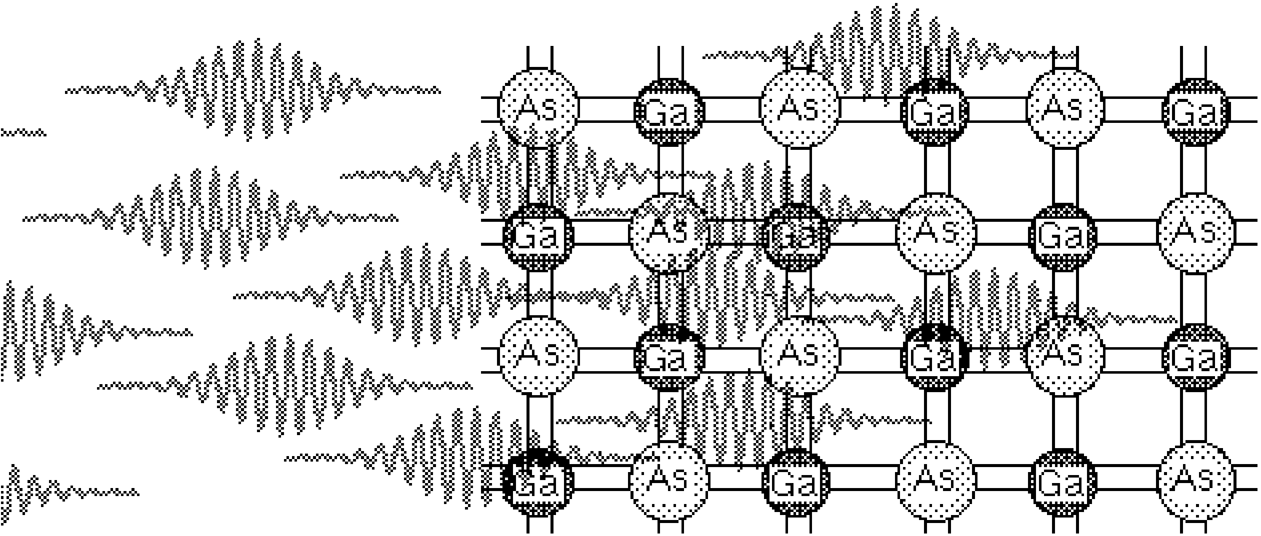
APS March Meeting
Los Angeles, CA
18 March 1998

INTRODUCTION



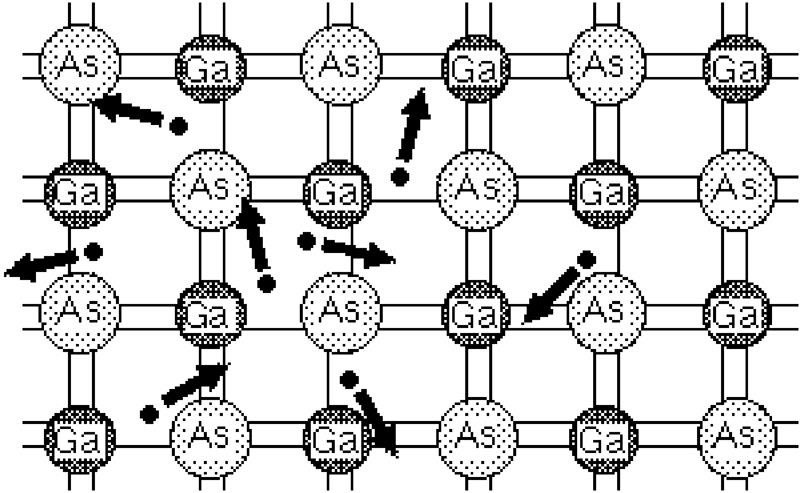
how does light melt a solid?

INTRODUCTION



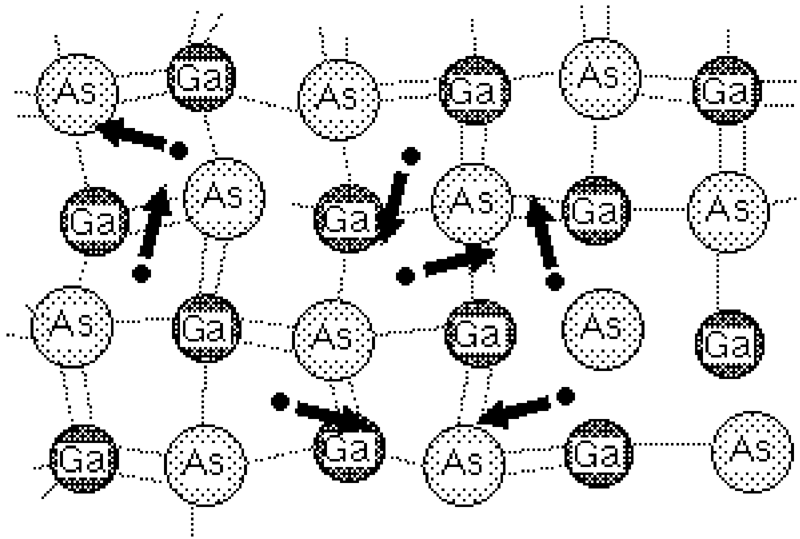
photons excite valence electrons...

INTRODUCTION



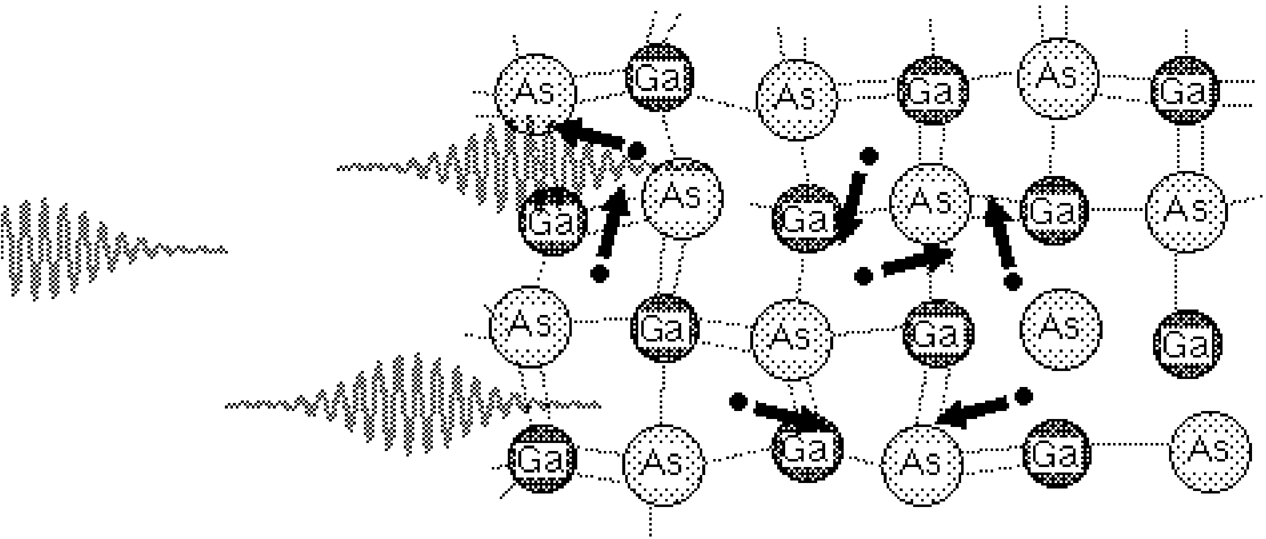
...and create free electrons...

INTRODUCTION



... causing electronic & structural changes...

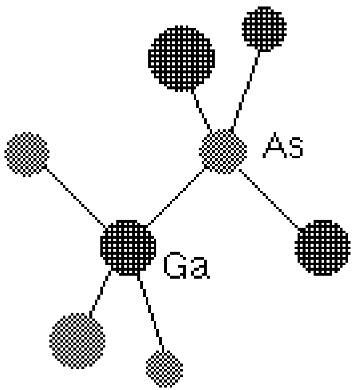
INTRODUCTION



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

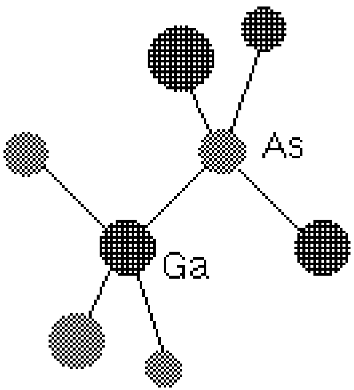
INTRODUCTION

structure



INTRODUCTION

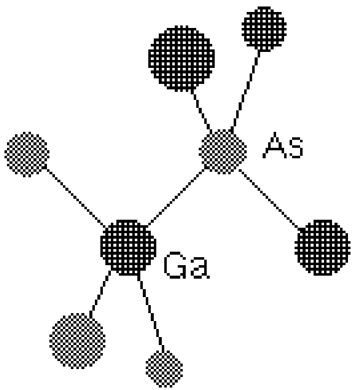
structure

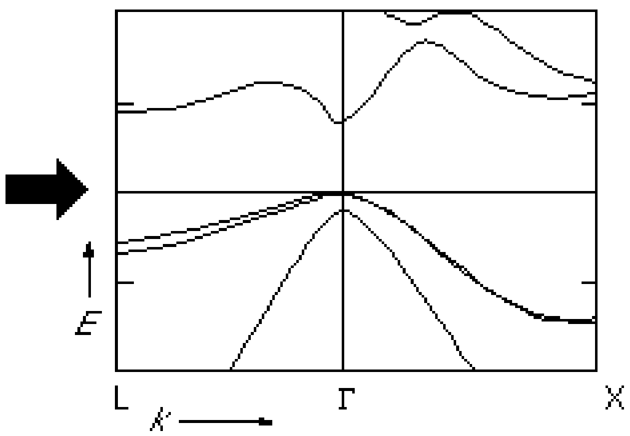


INTRODUCTION

structure

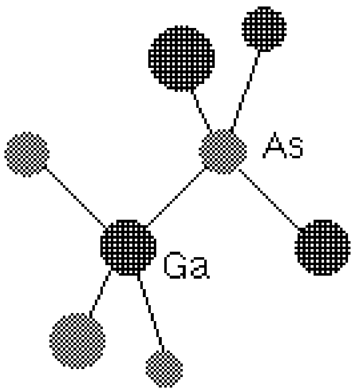
bandstructure



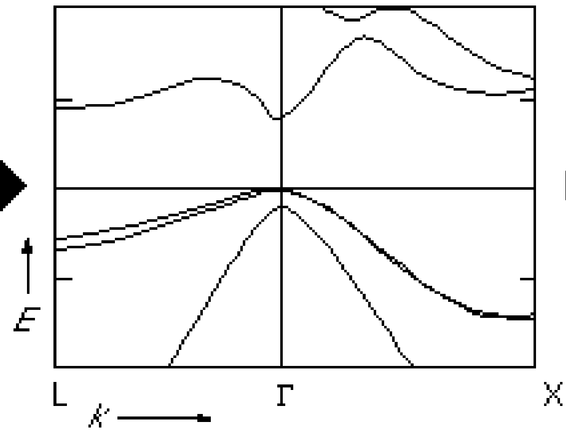


INTRODUCTION

structure

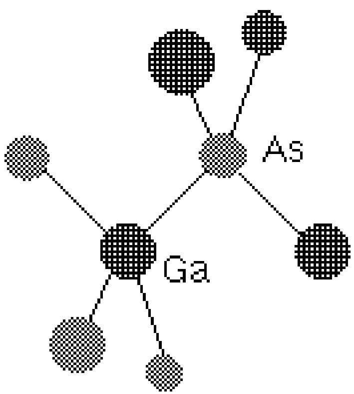


bandstructure



INTRODUCTION

structure



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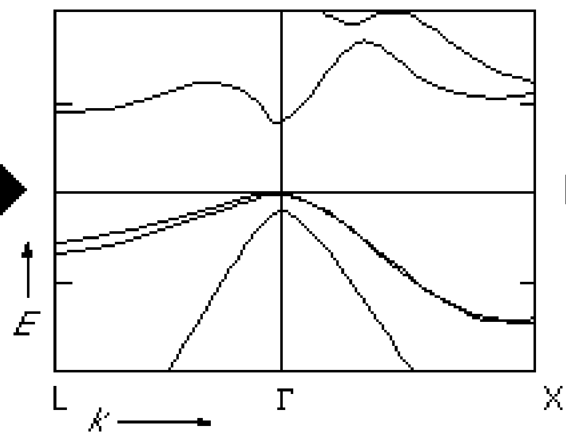
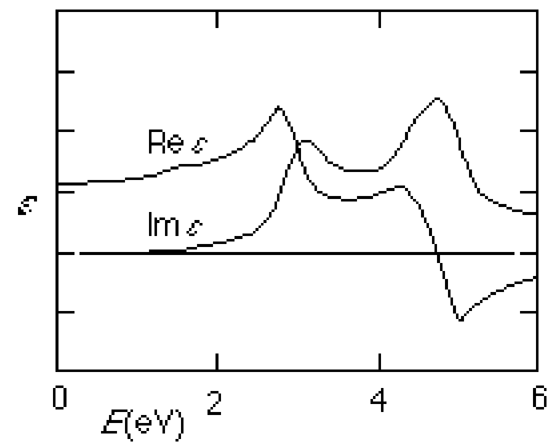
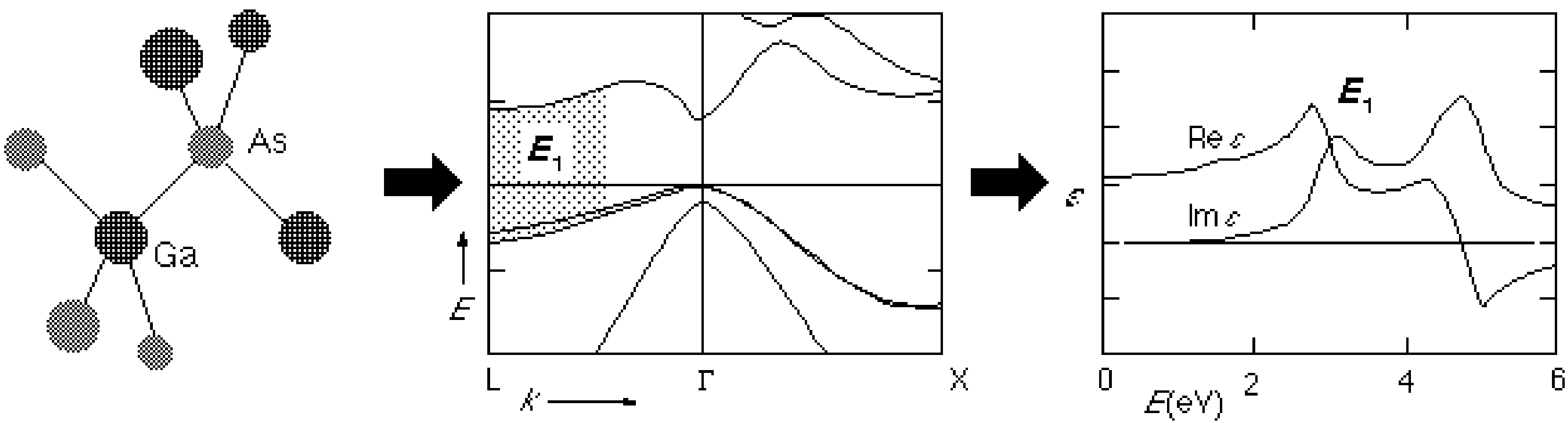


dielectric function



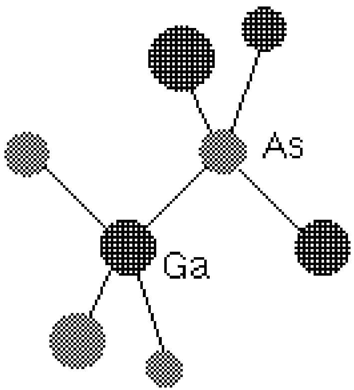
INTRODUCTION

structure | bandstructure | dielectric function



INTRODUCTION

structure



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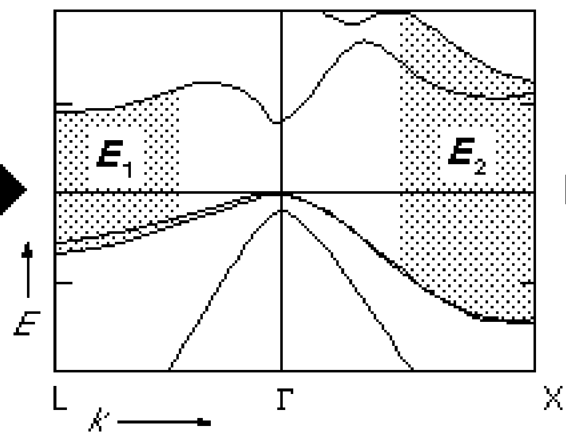

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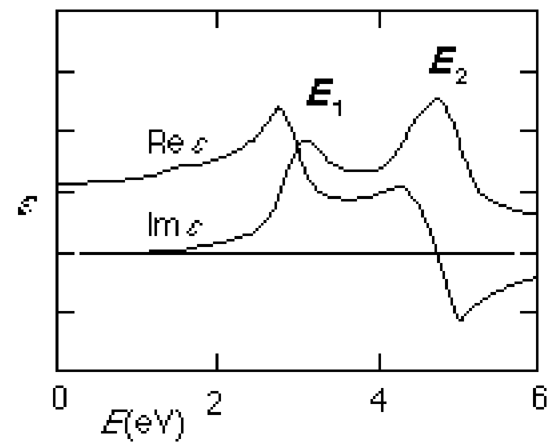
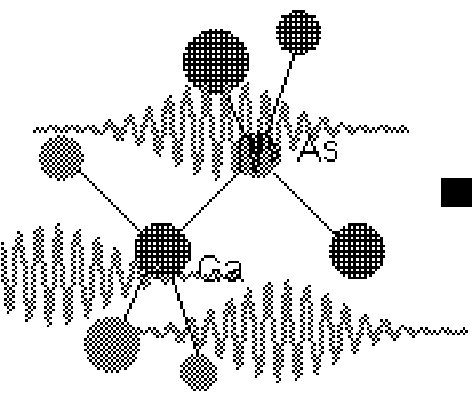


INTRODUCTION

structure



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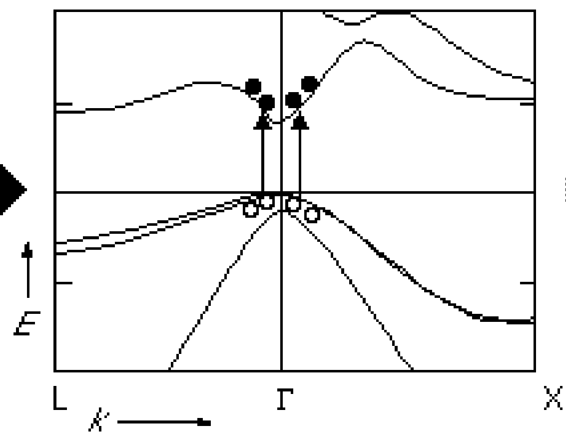

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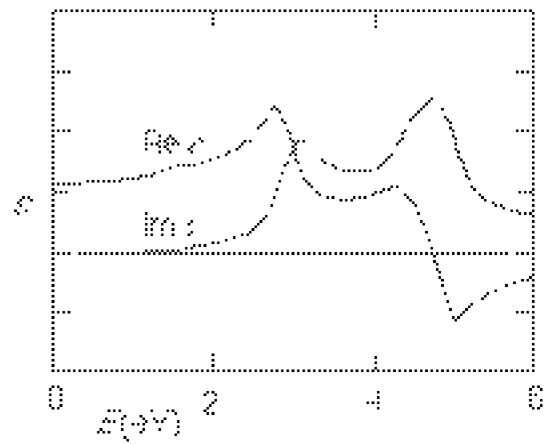


70 fs, 10^{16} W/m^2

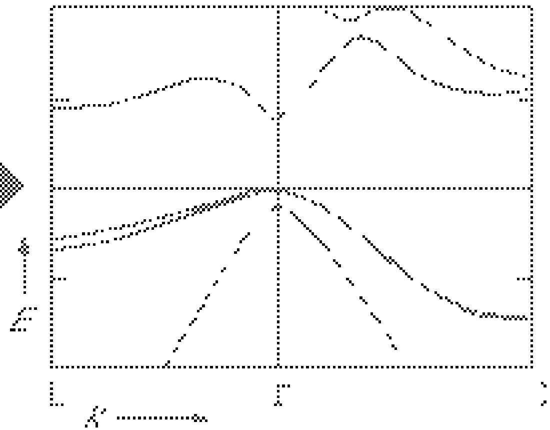
$10^{20} - 10^{22}$ cm^{-3}

INTRODUCTION

structure

?

bandstructure



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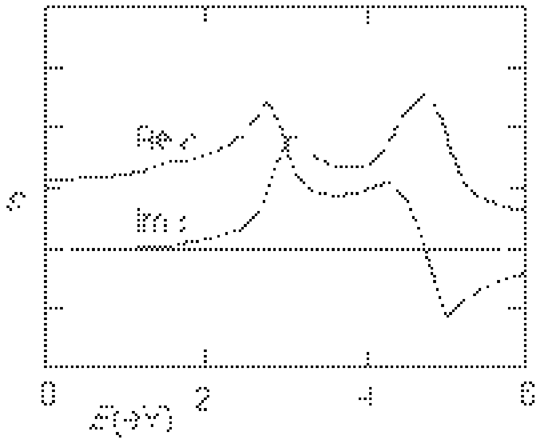
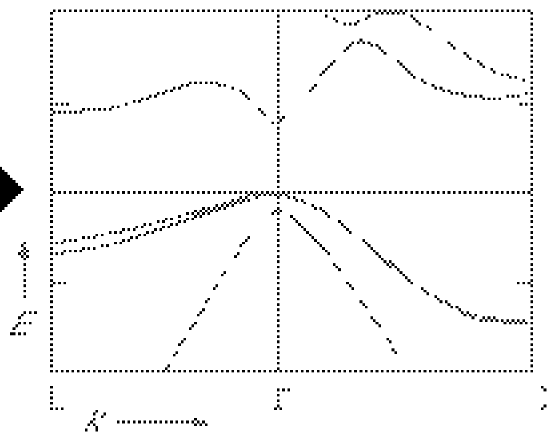


INTRODUCTION

structure

?

bandstructure



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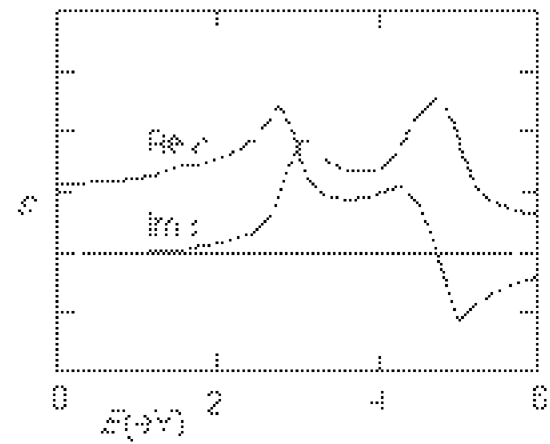
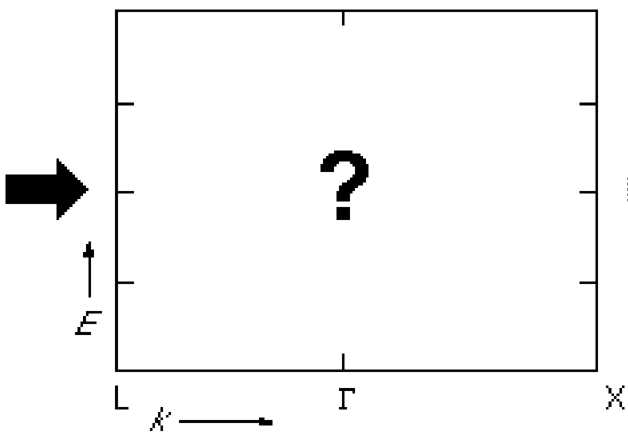


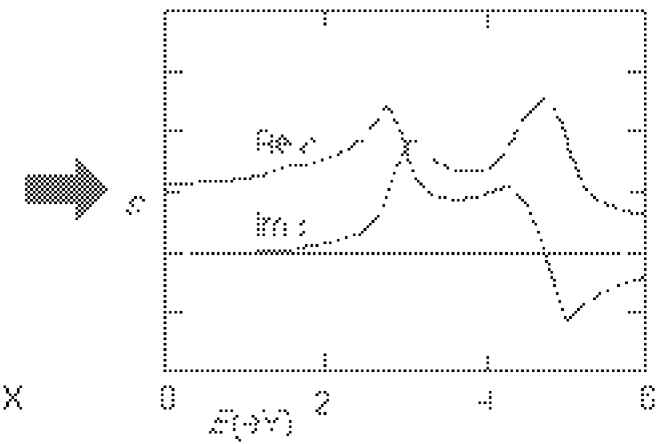
INTRODUCTION

structure

bandstructure

dielectric function

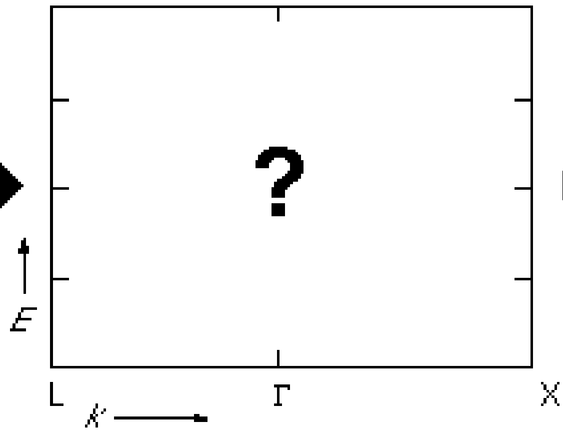


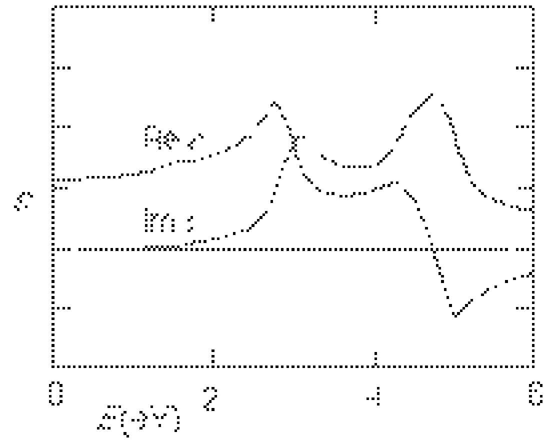


INTRODUCTION

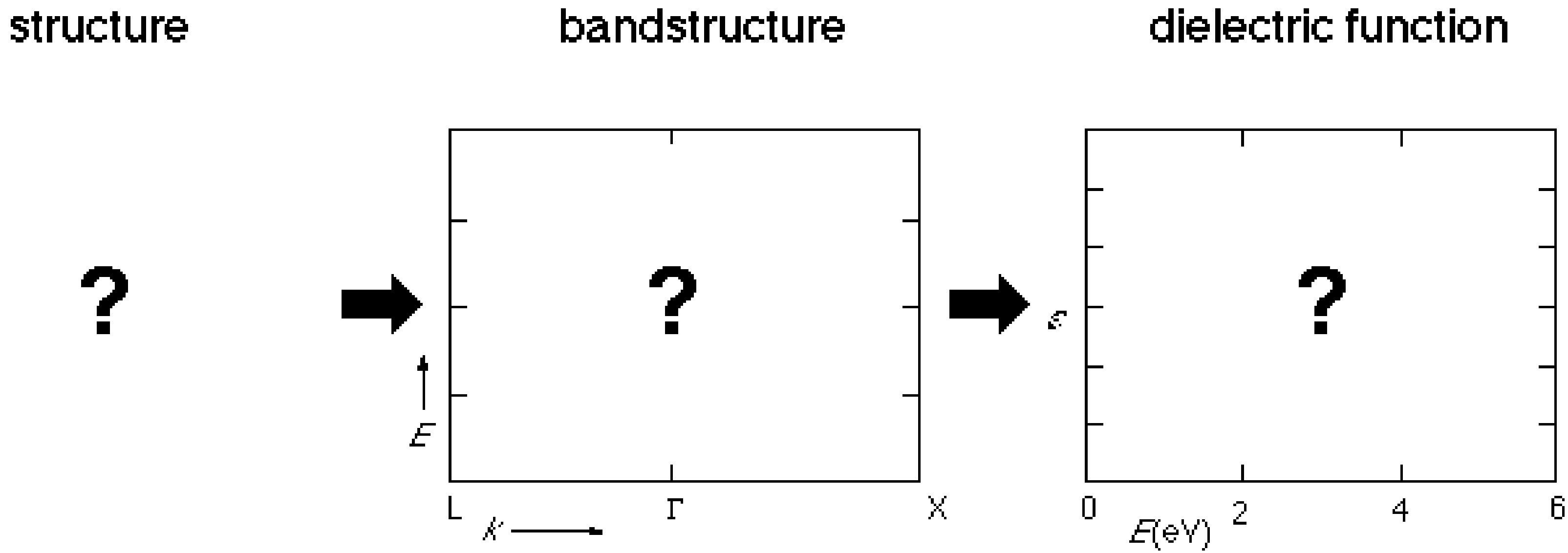
structure | bandstructure | dielectric function

?





INTRODUCTION

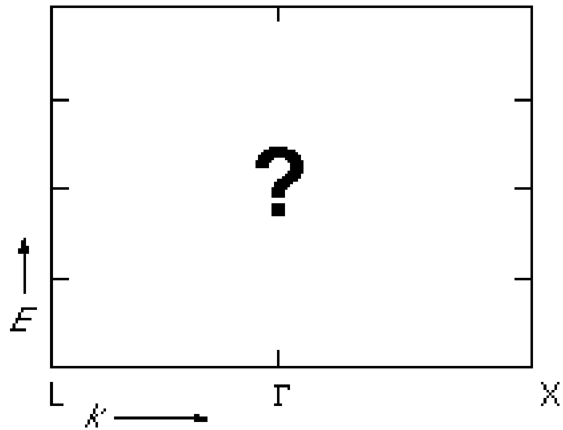


INTRODUCTION

structure

?

bandstructure



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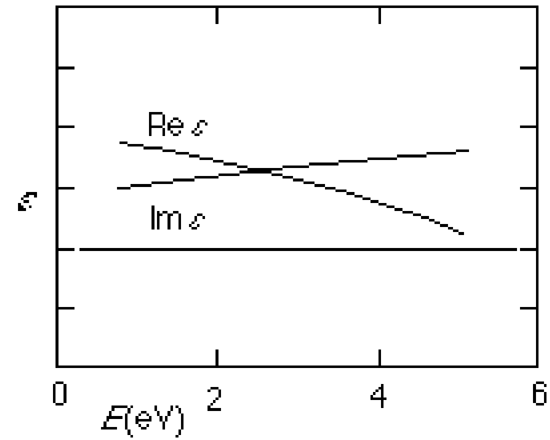
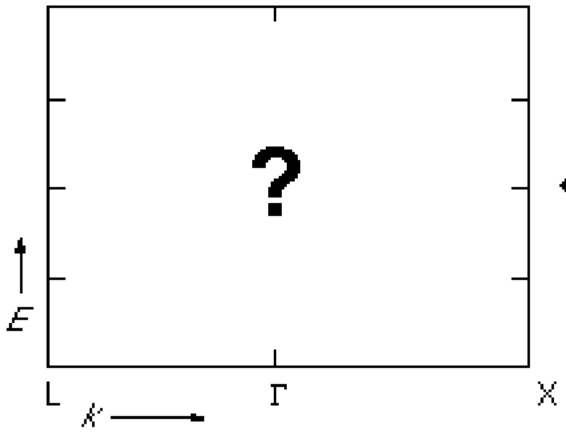


INTRODUCTION

structure

?

bandstructure



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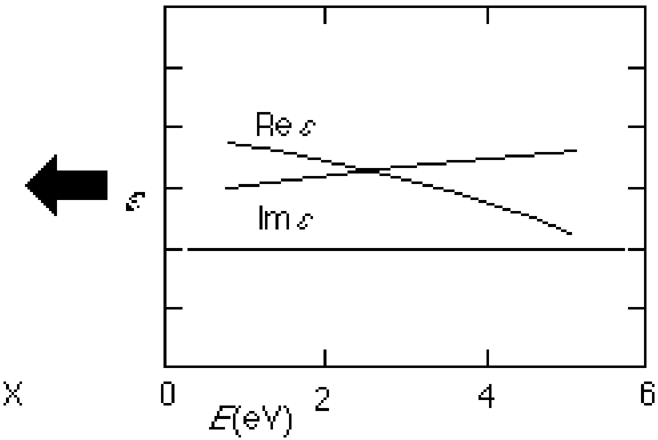
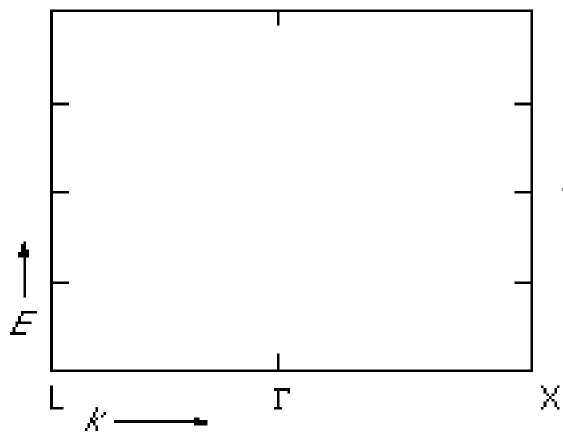
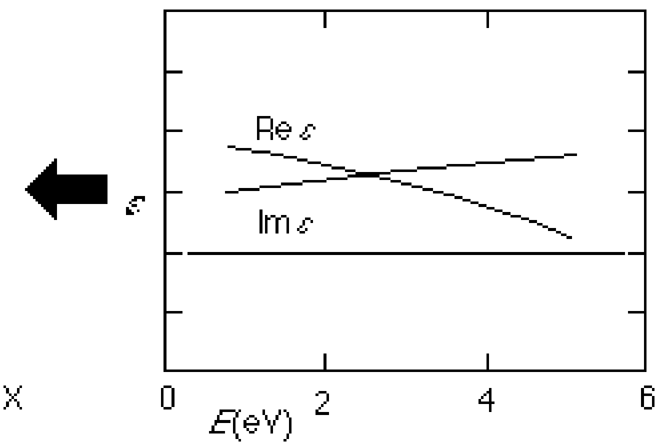


INTRODUCTION

structure

?



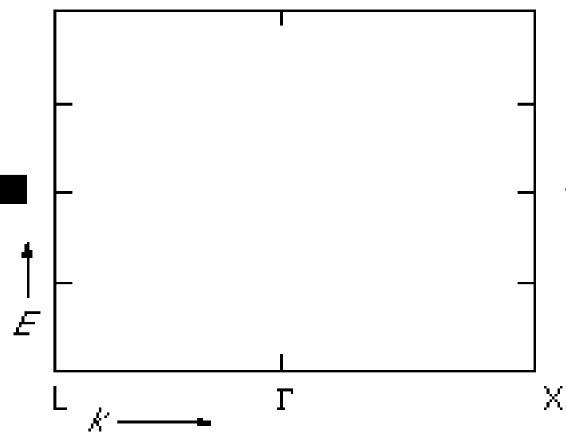


INTRODUCTION

structure

?

bandstructure



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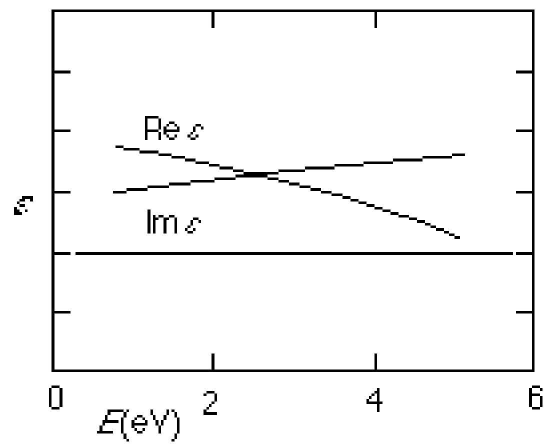
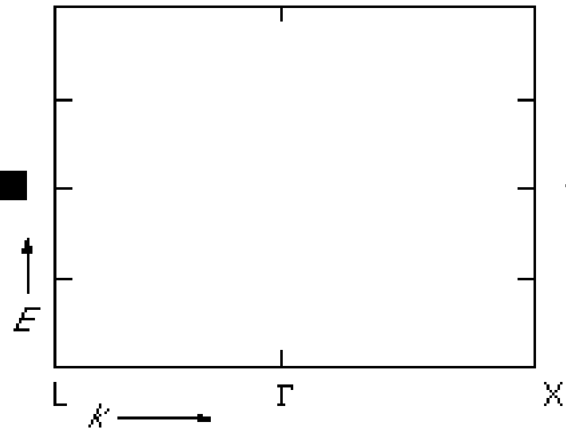


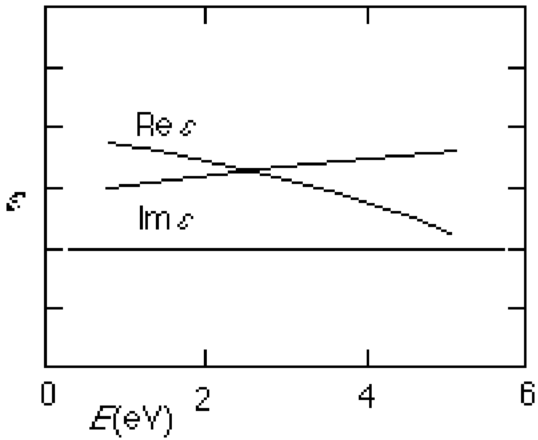
INTRODUCTION

structure

bandstructure

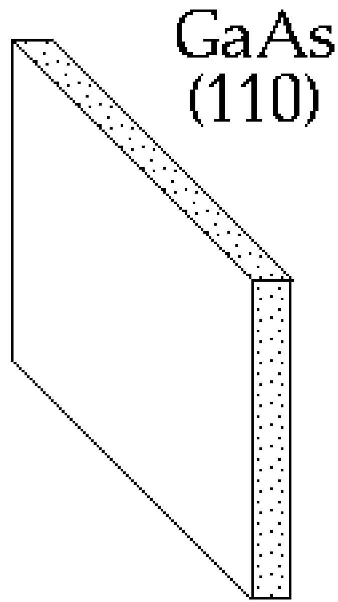
dielectric function





1. Method
2. Results
3. Discussion

2.2 eV DIELECTRIC CONSTANT



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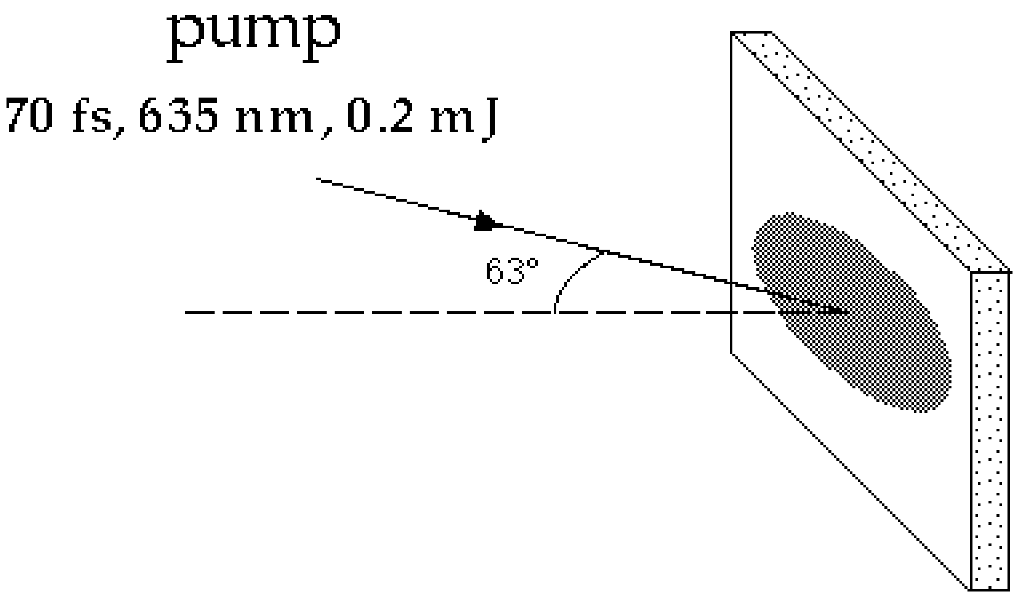

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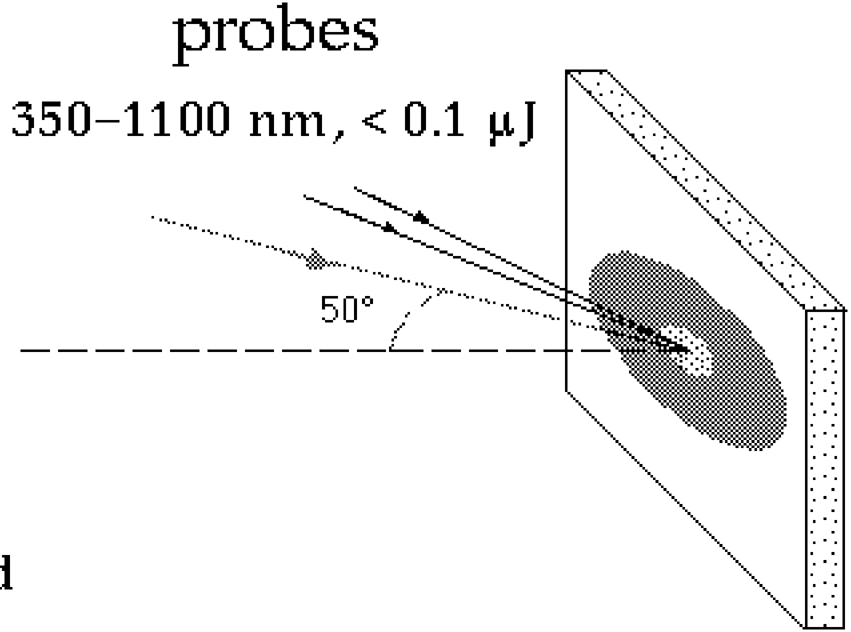
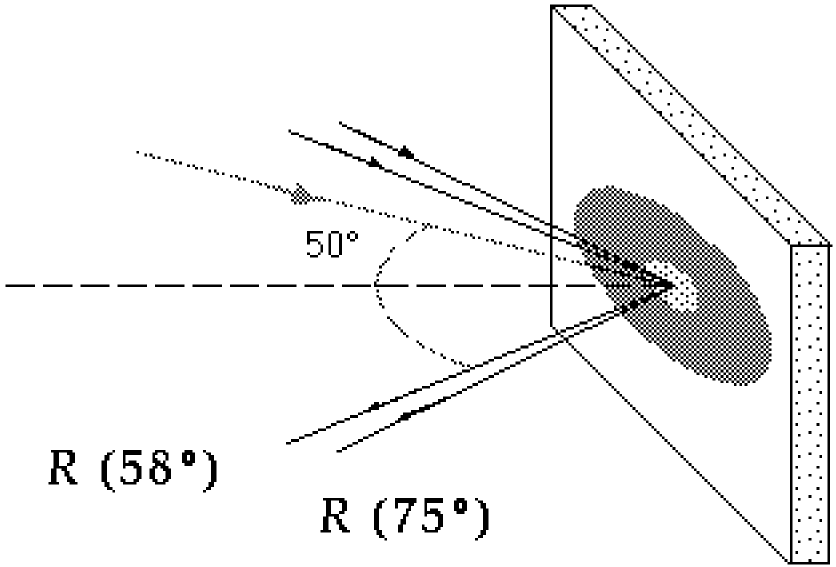
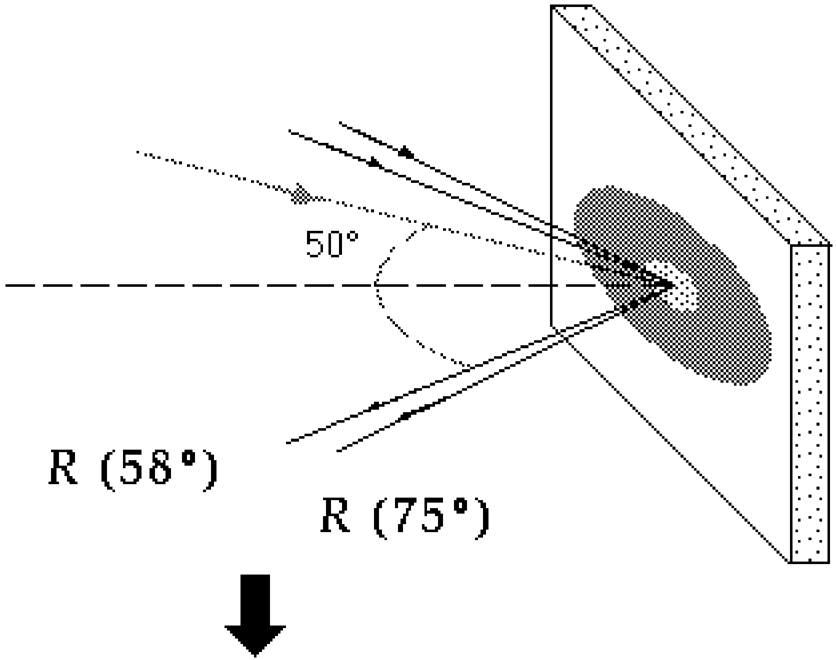


all beams
p-polarized

2.2 eV DIELECTRIC CONSTANT

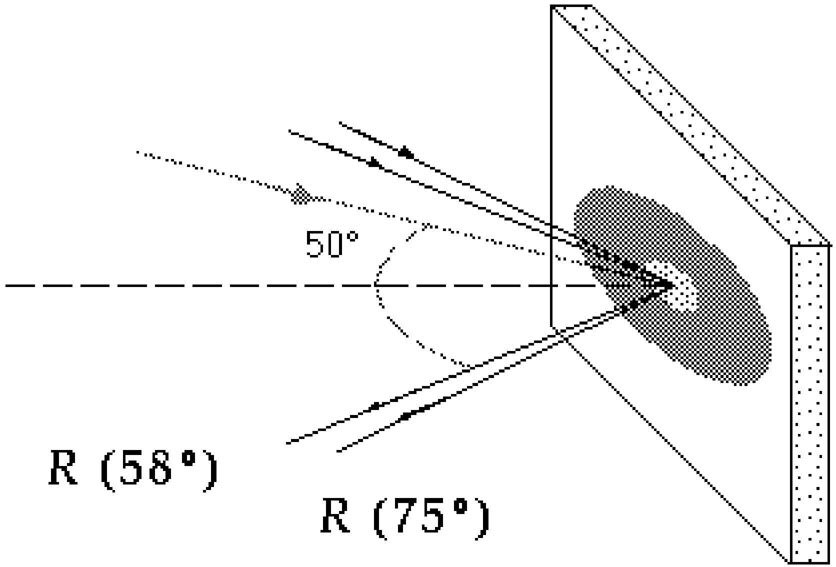


2.2 eV DIELECTRIC CONSTANT



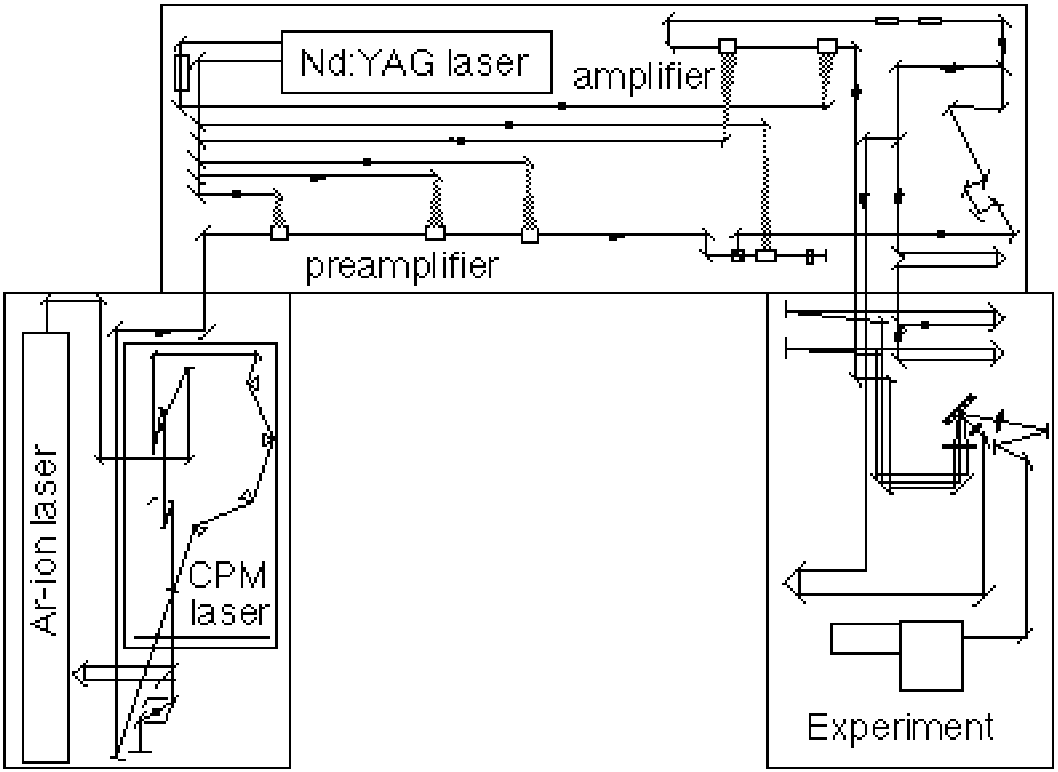
Fresnel equations

2.2 eV DIELECTRIC CONSTANT



Fresnel equations → Re $\varepsilon(\omega)$, Im $\varepsilon(\omega)$

SETUP

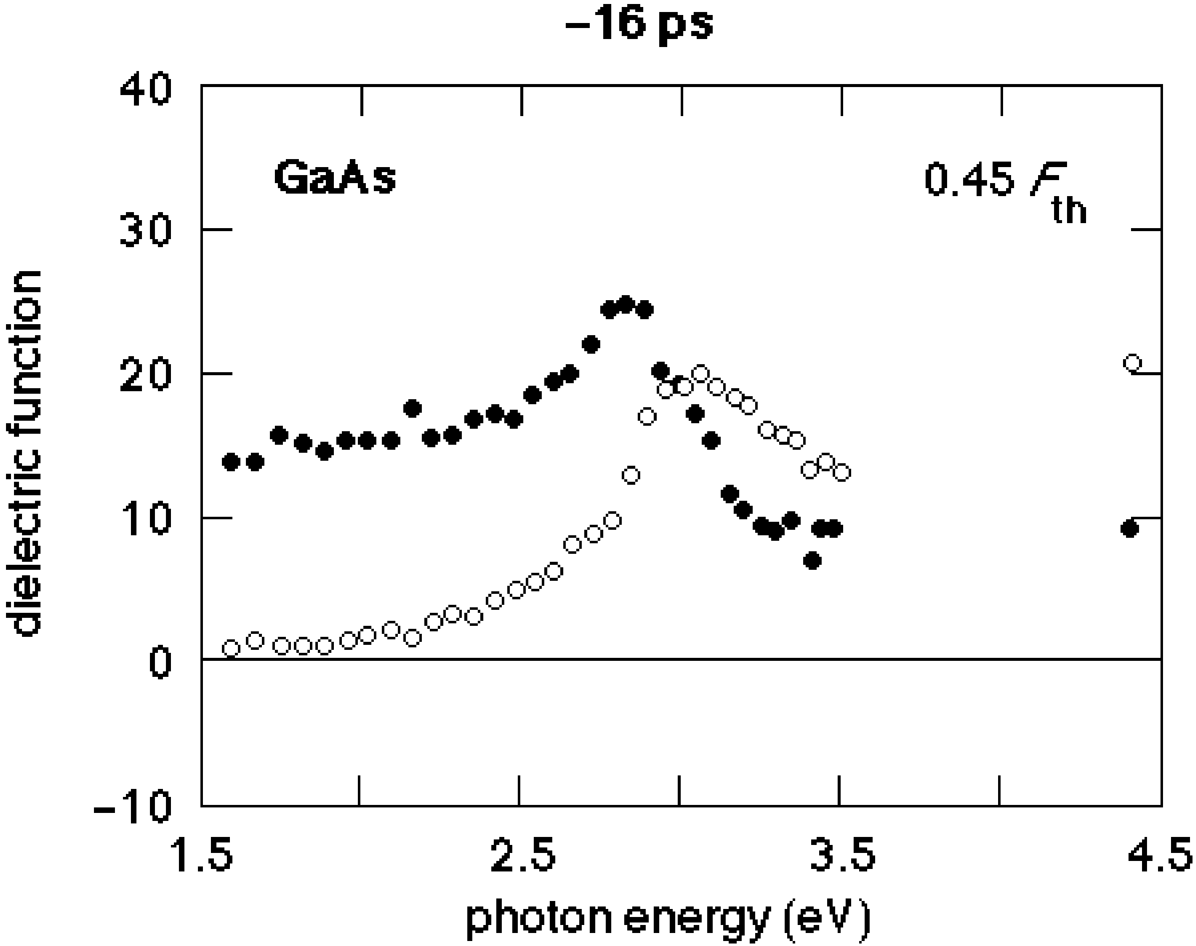


Nd:YAG laser
amplifier
preamplifier
Ar-ion laser
CPM
laser
Experiment

OUTLINE

1. Method
2. Results
3. Discussion

LOW FLUENCE DATA



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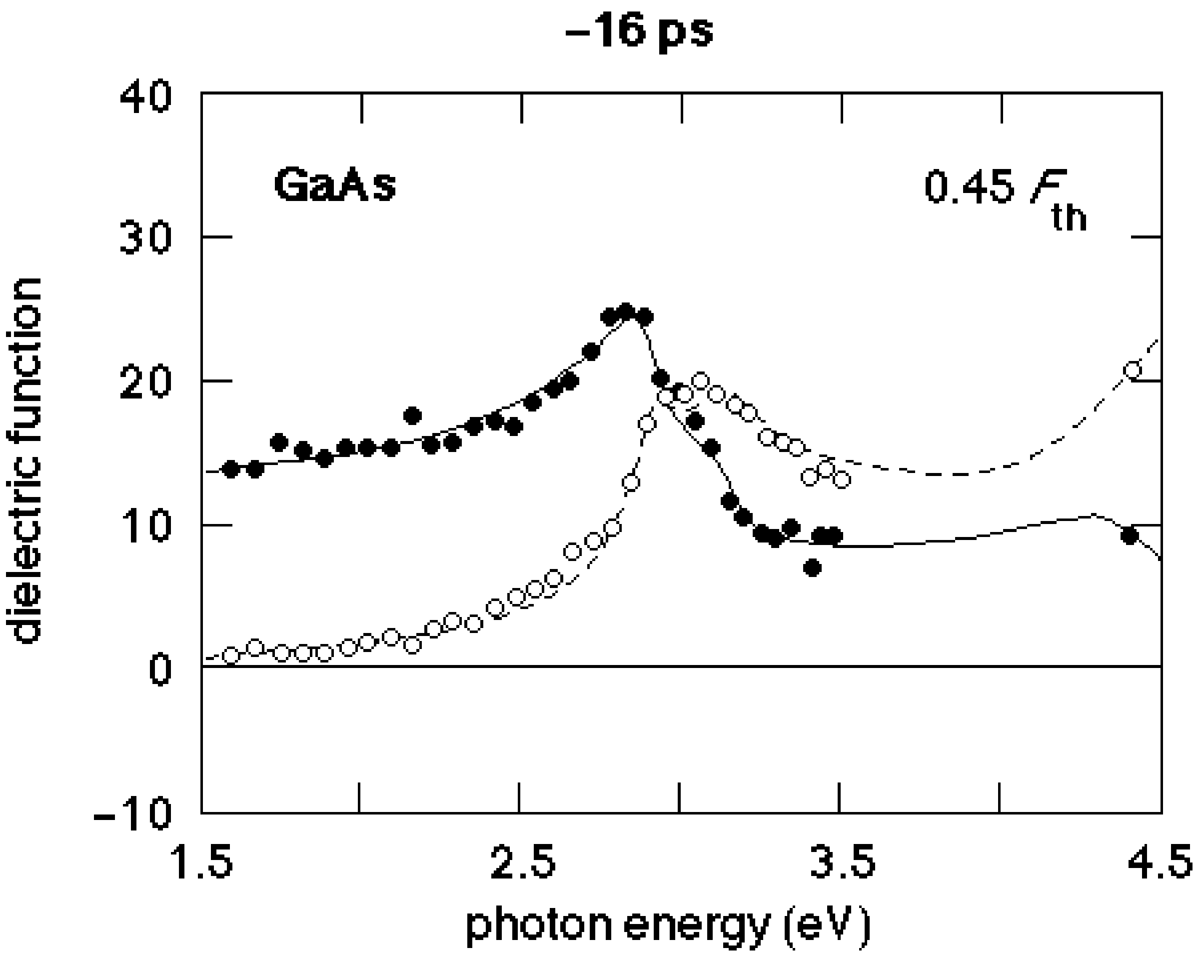

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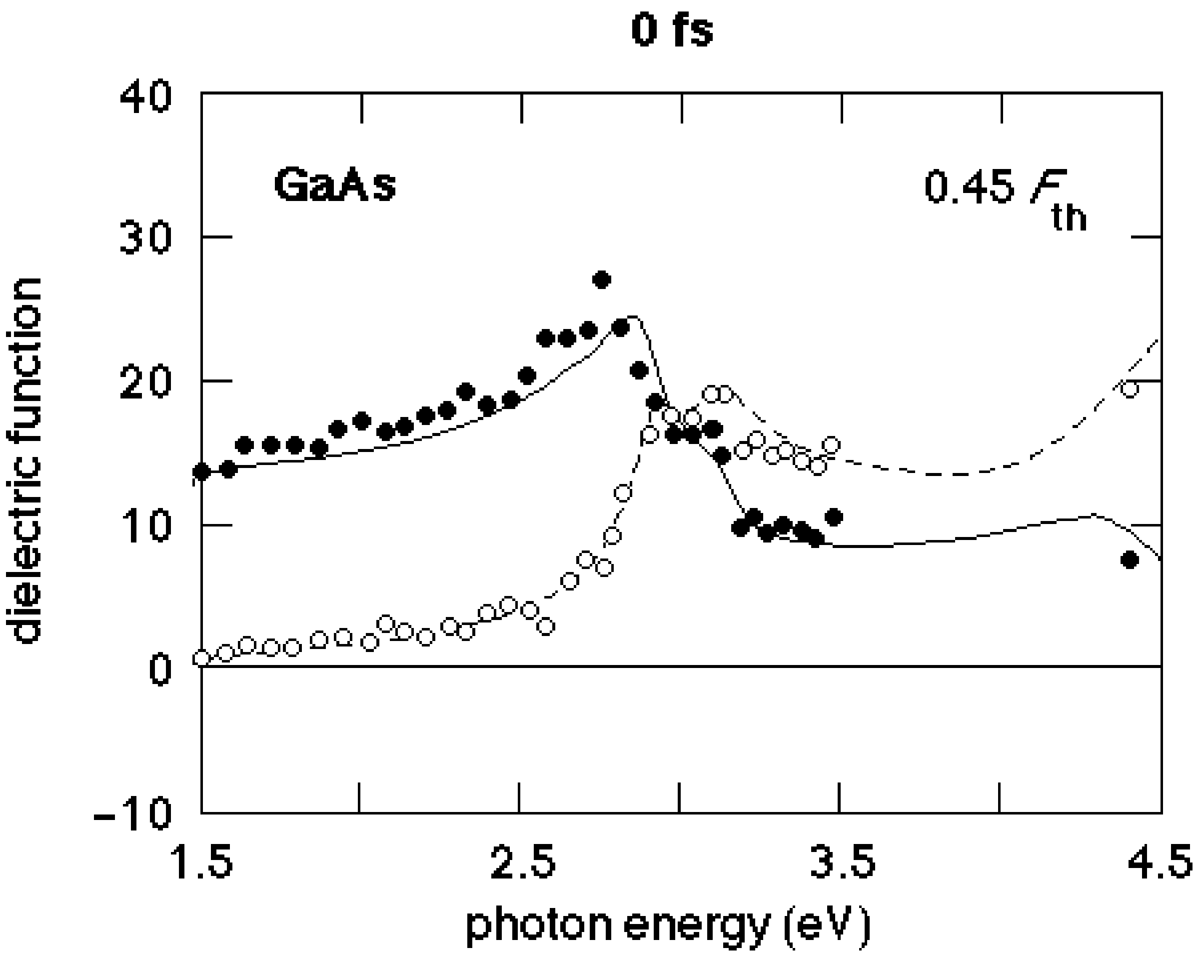

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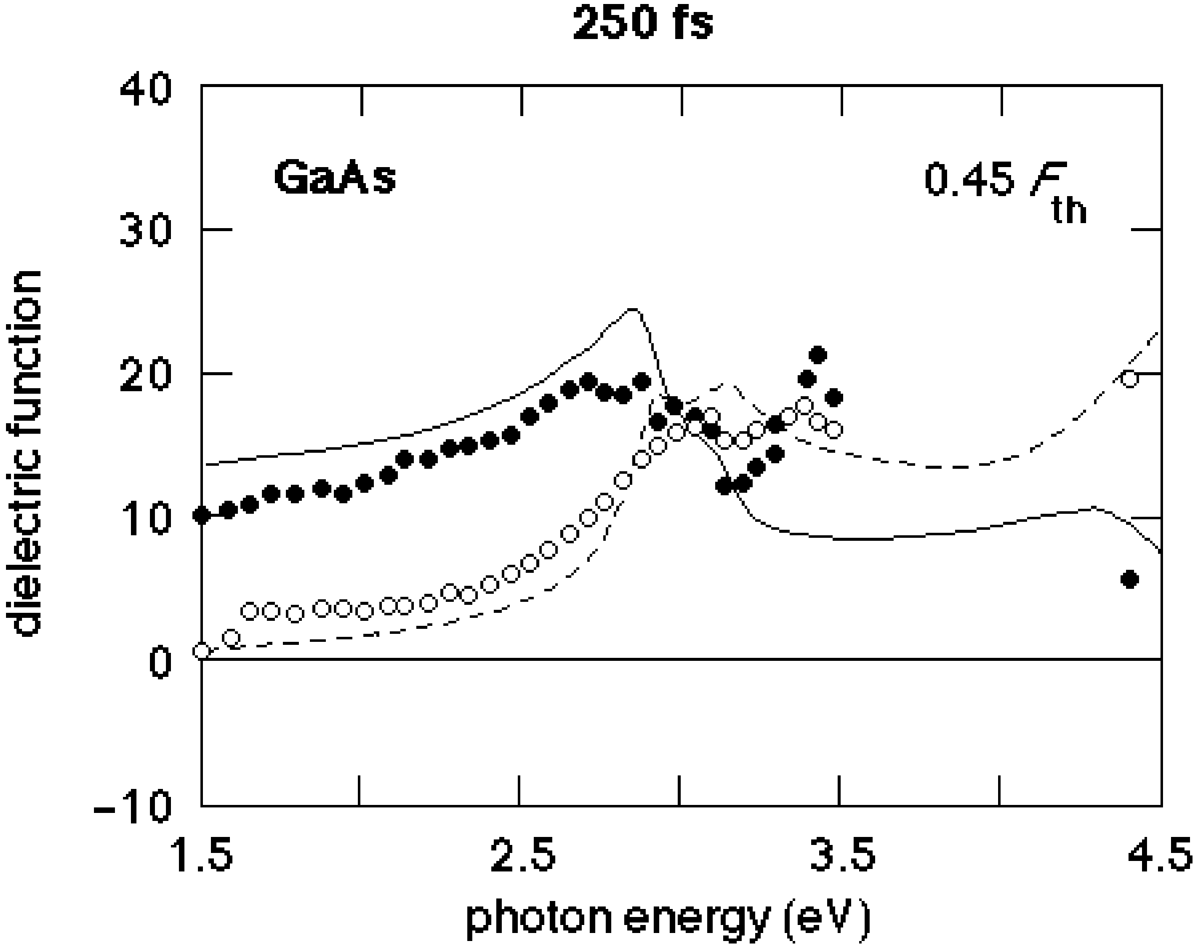

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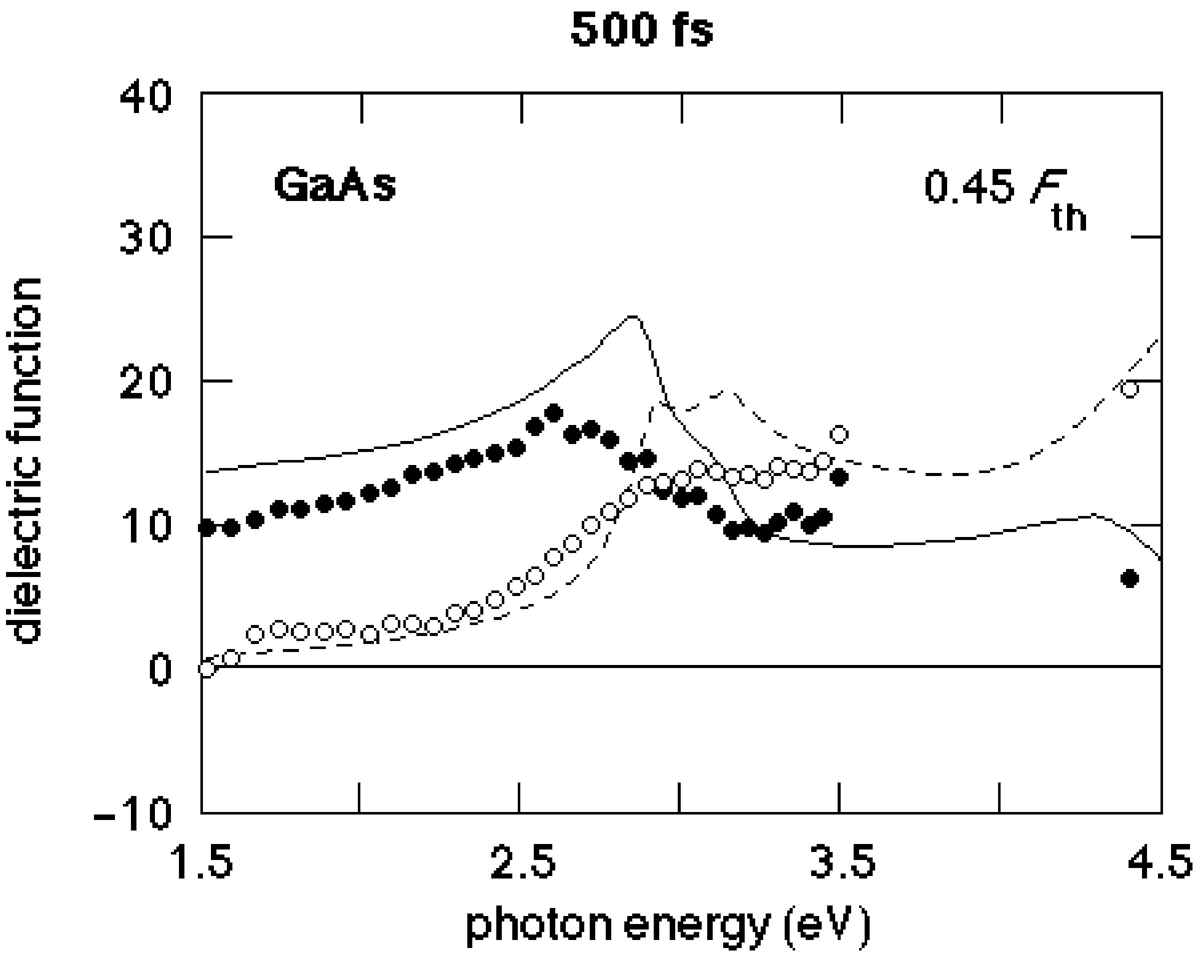

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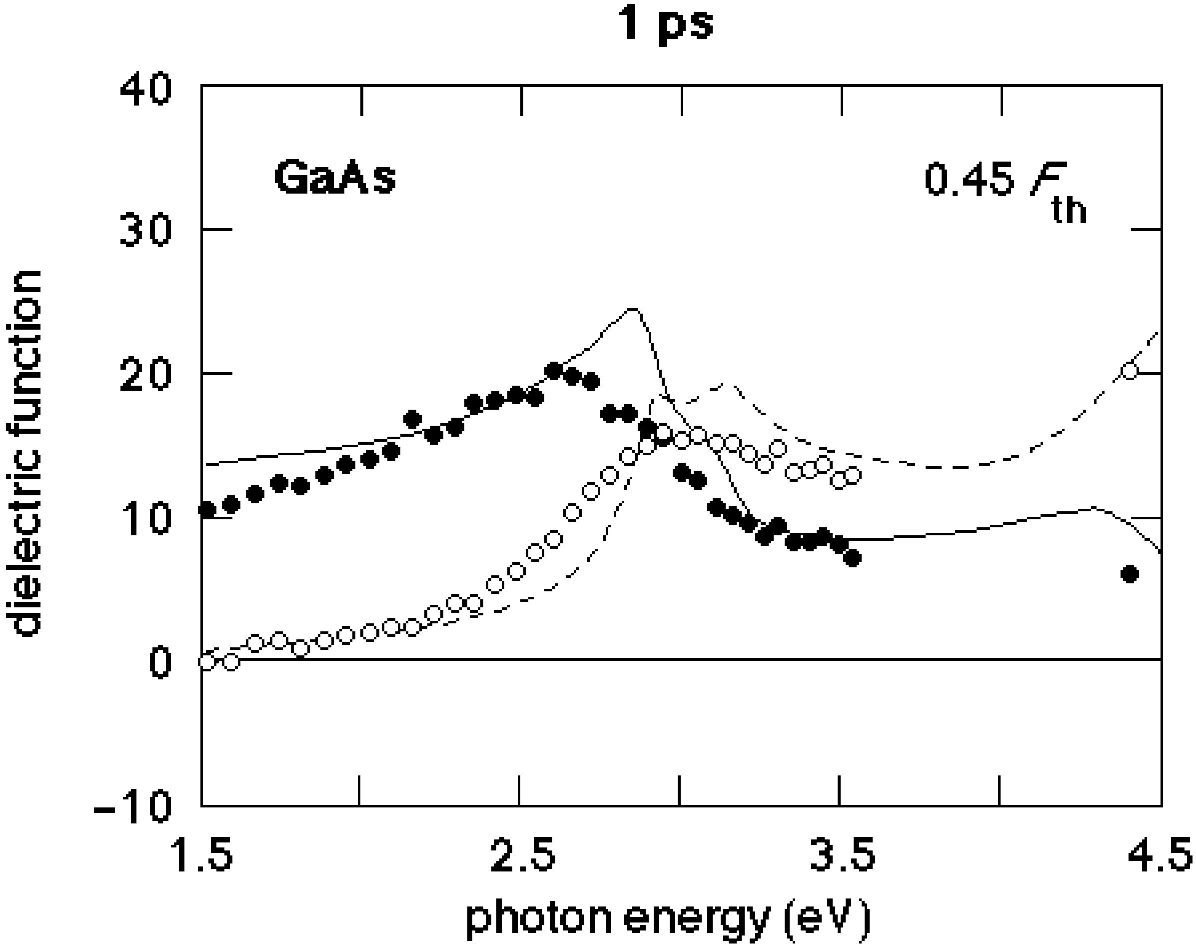

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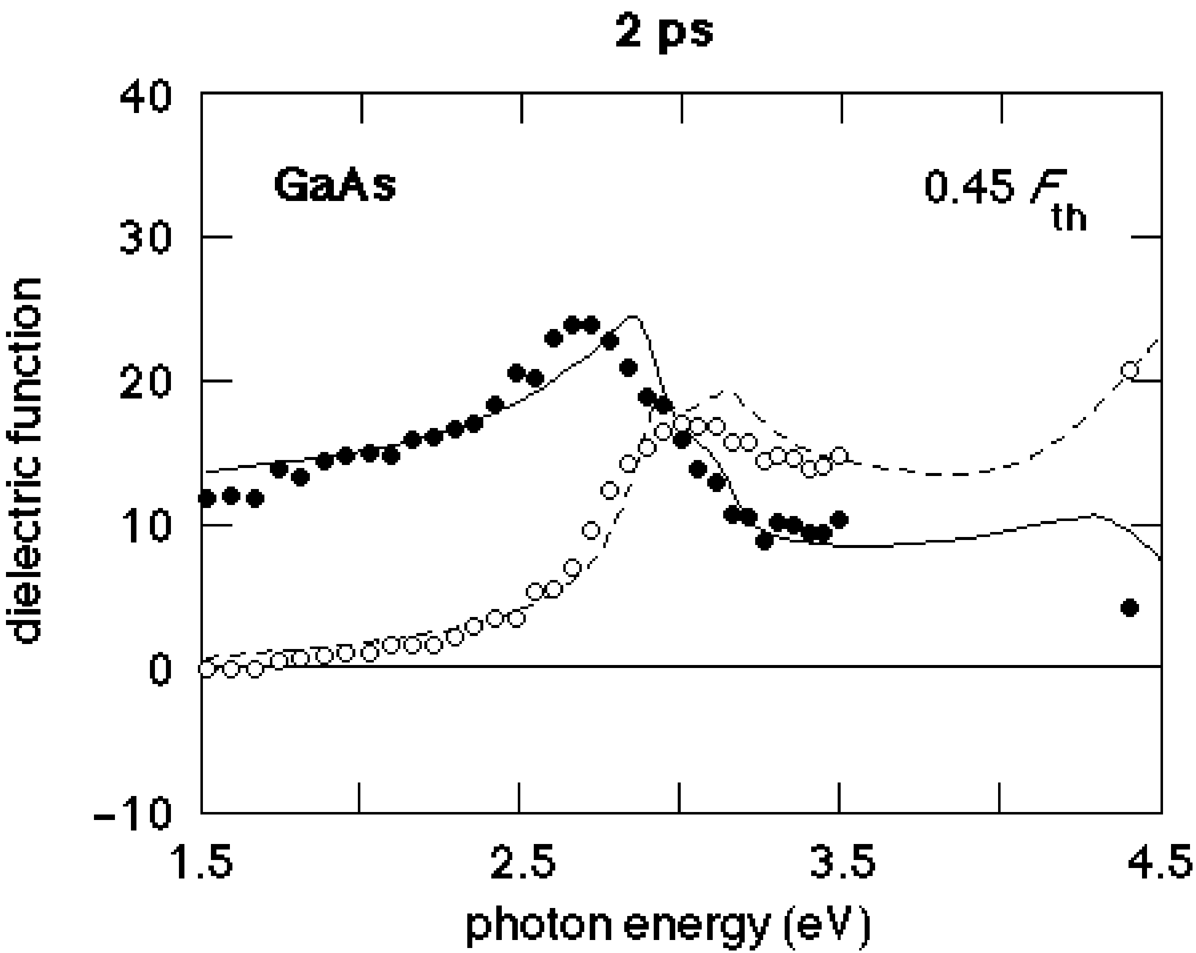

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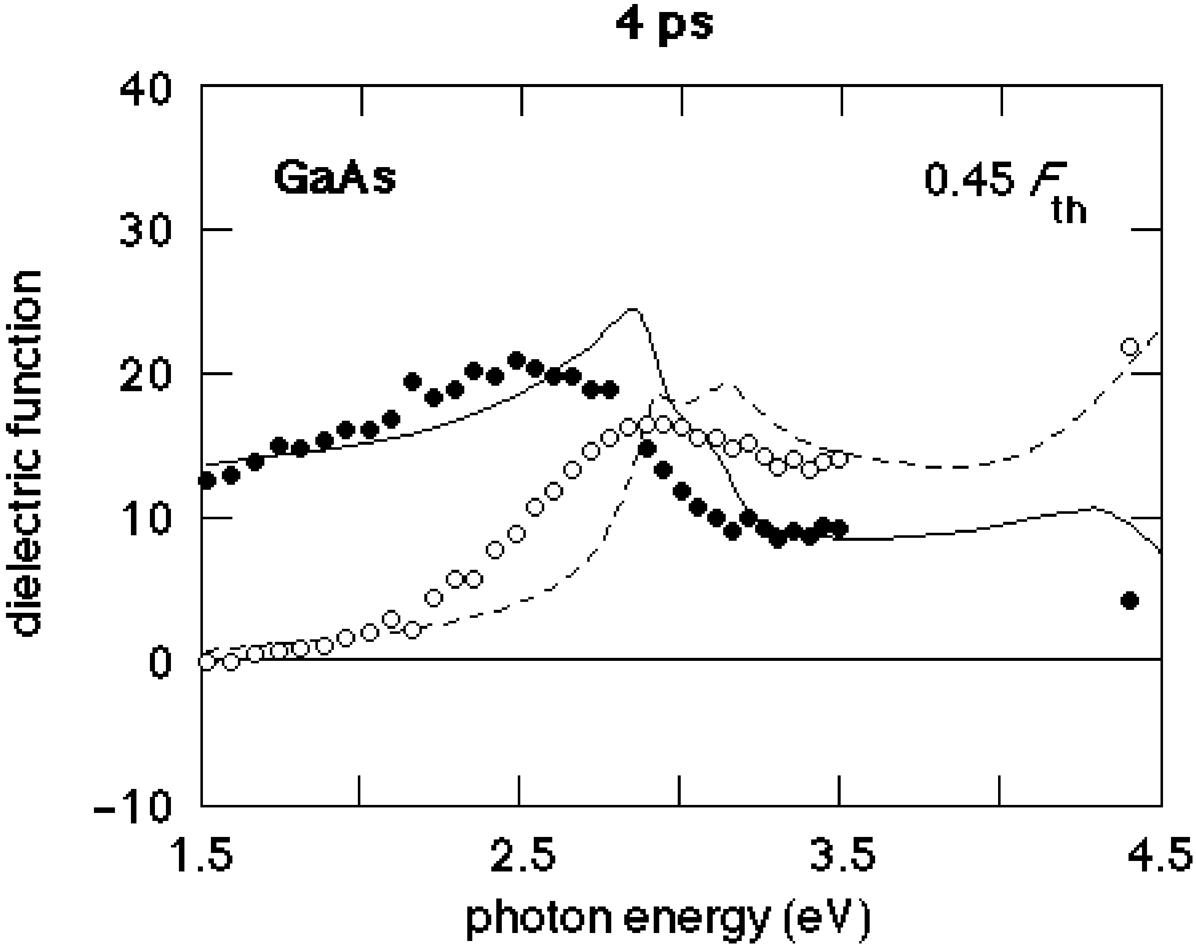

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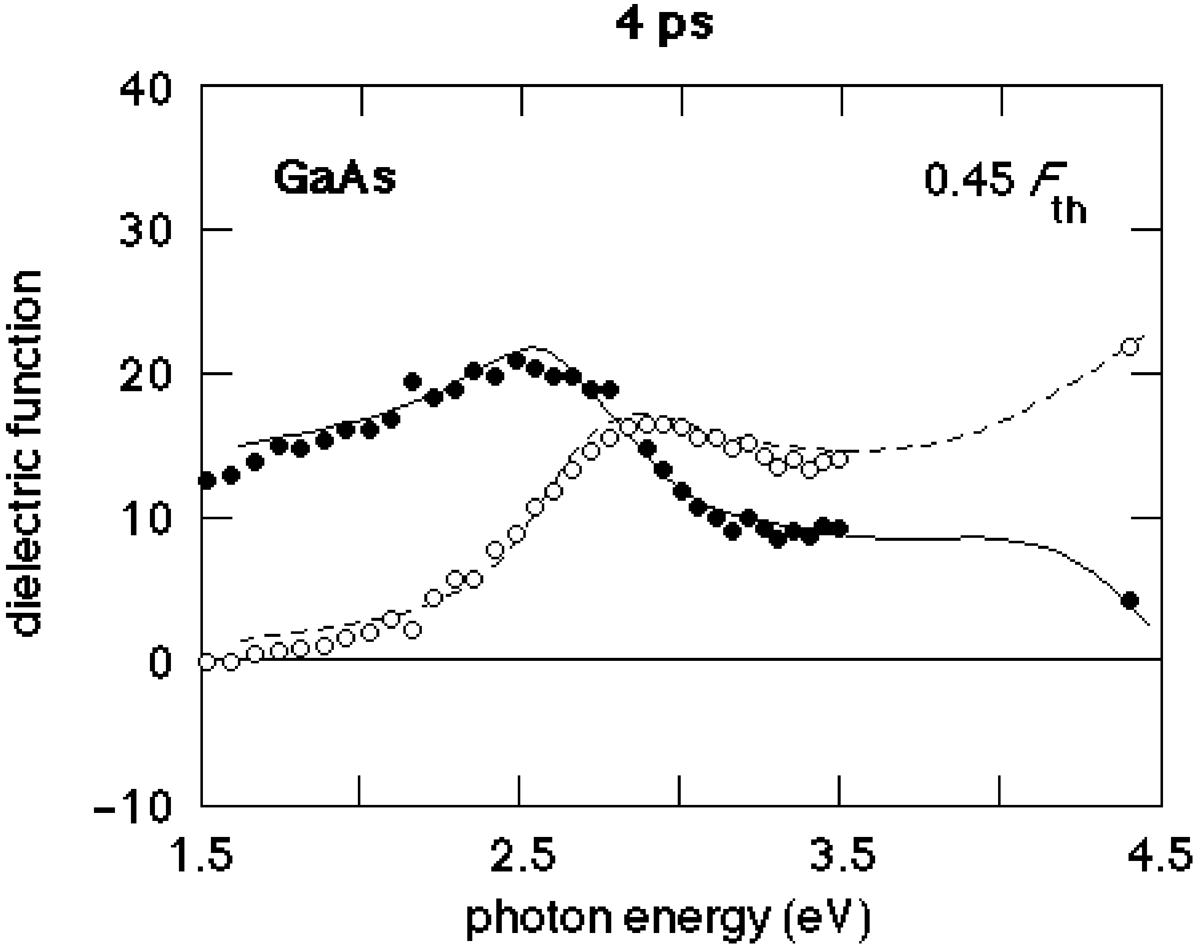

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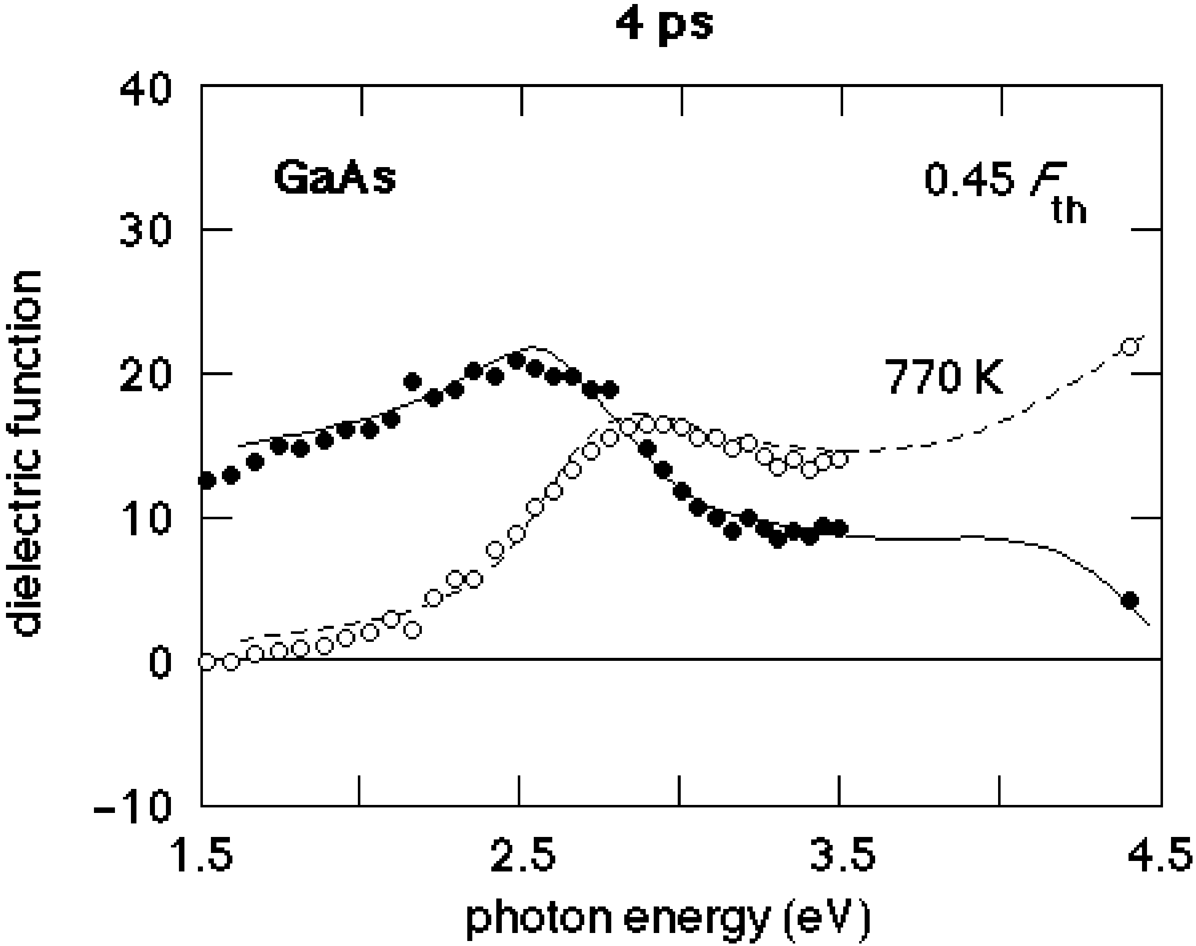

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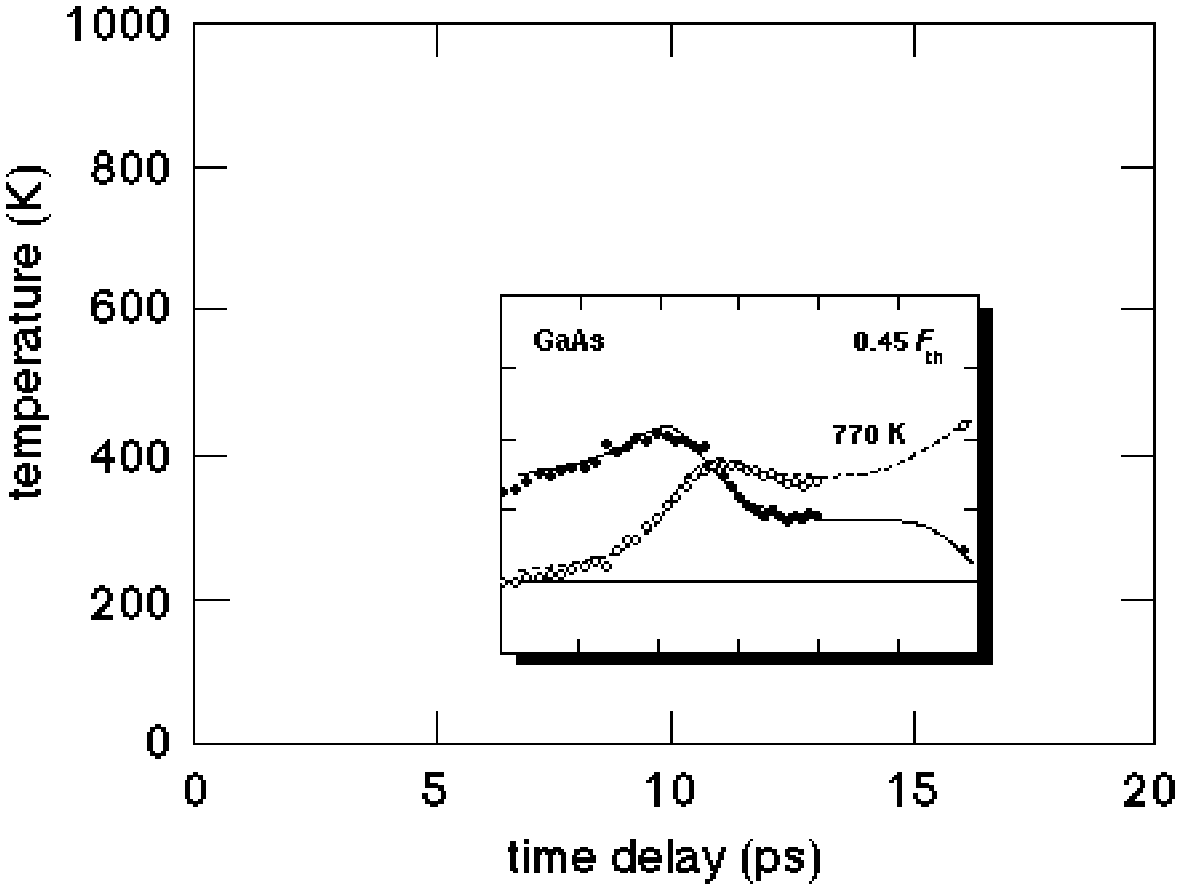

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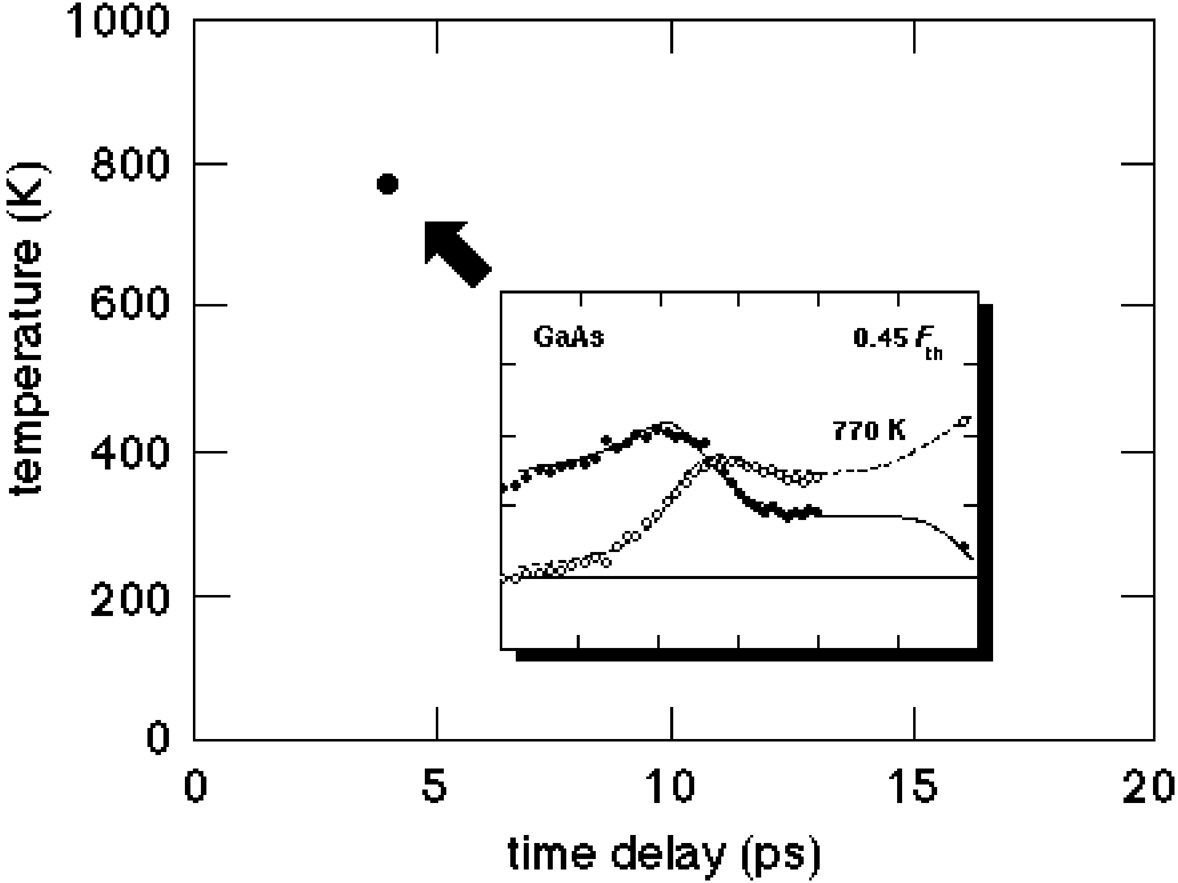

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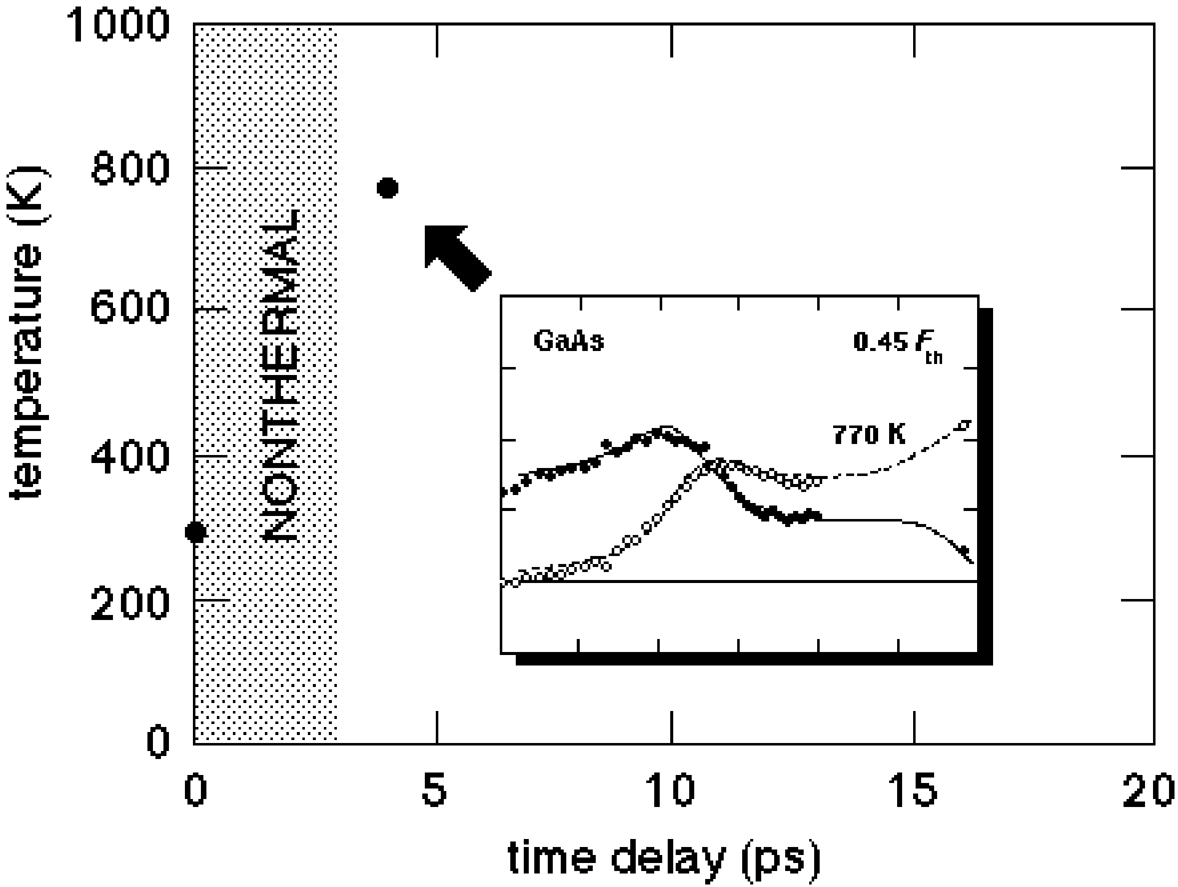

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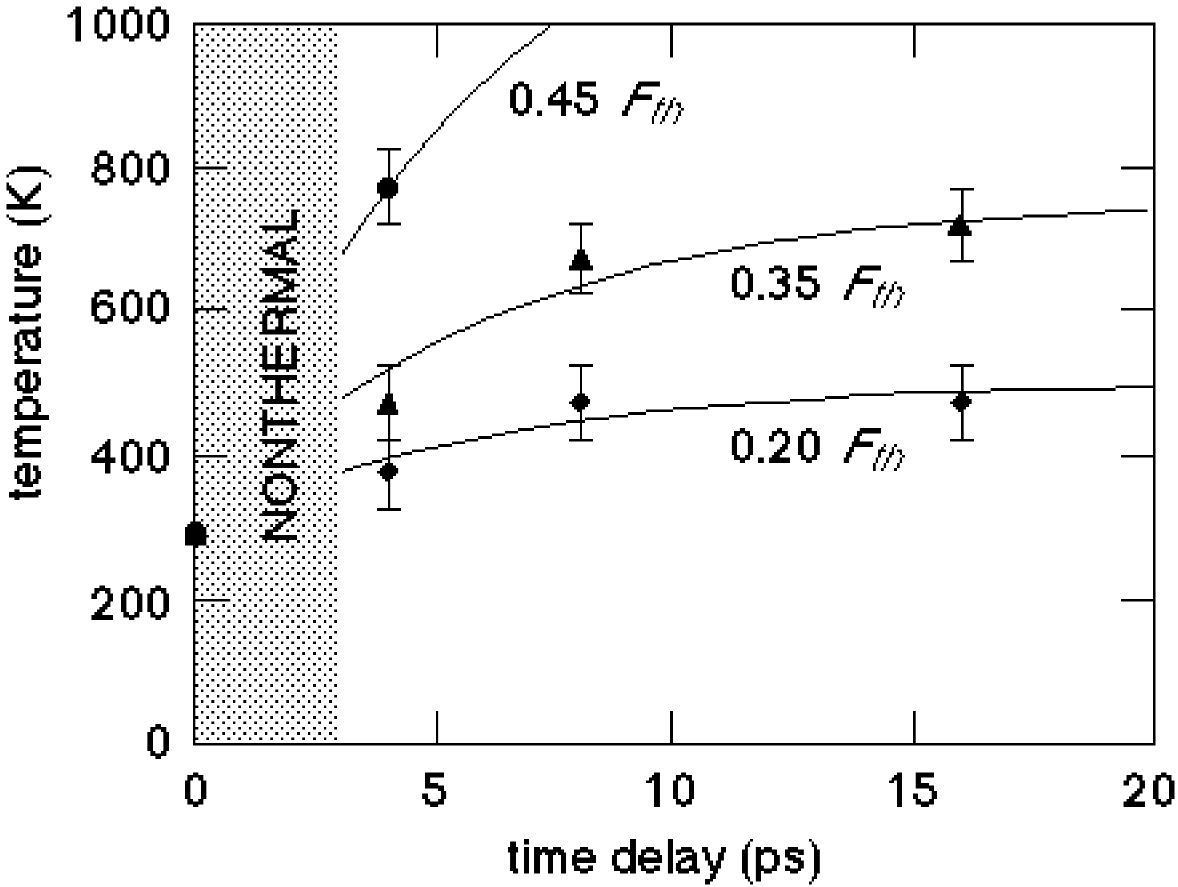

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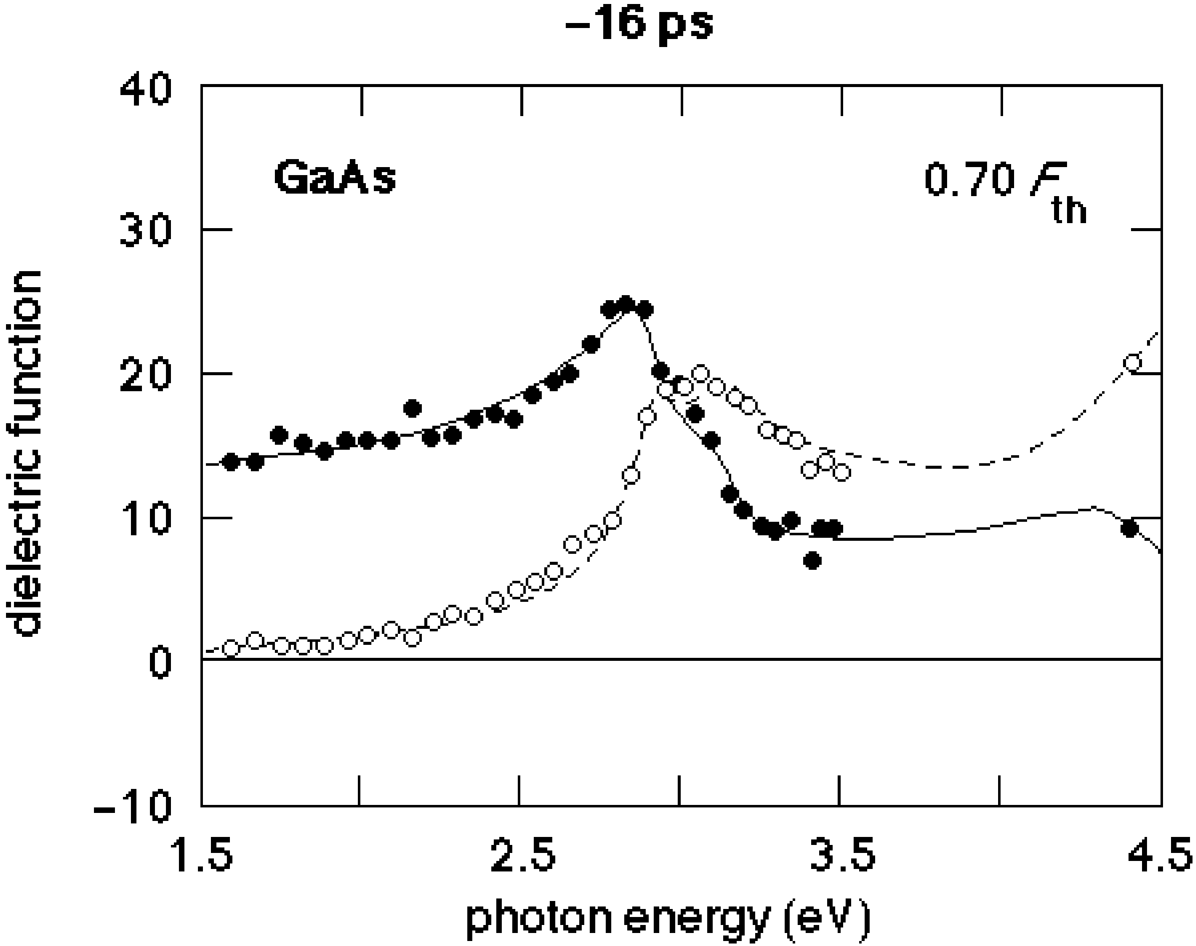

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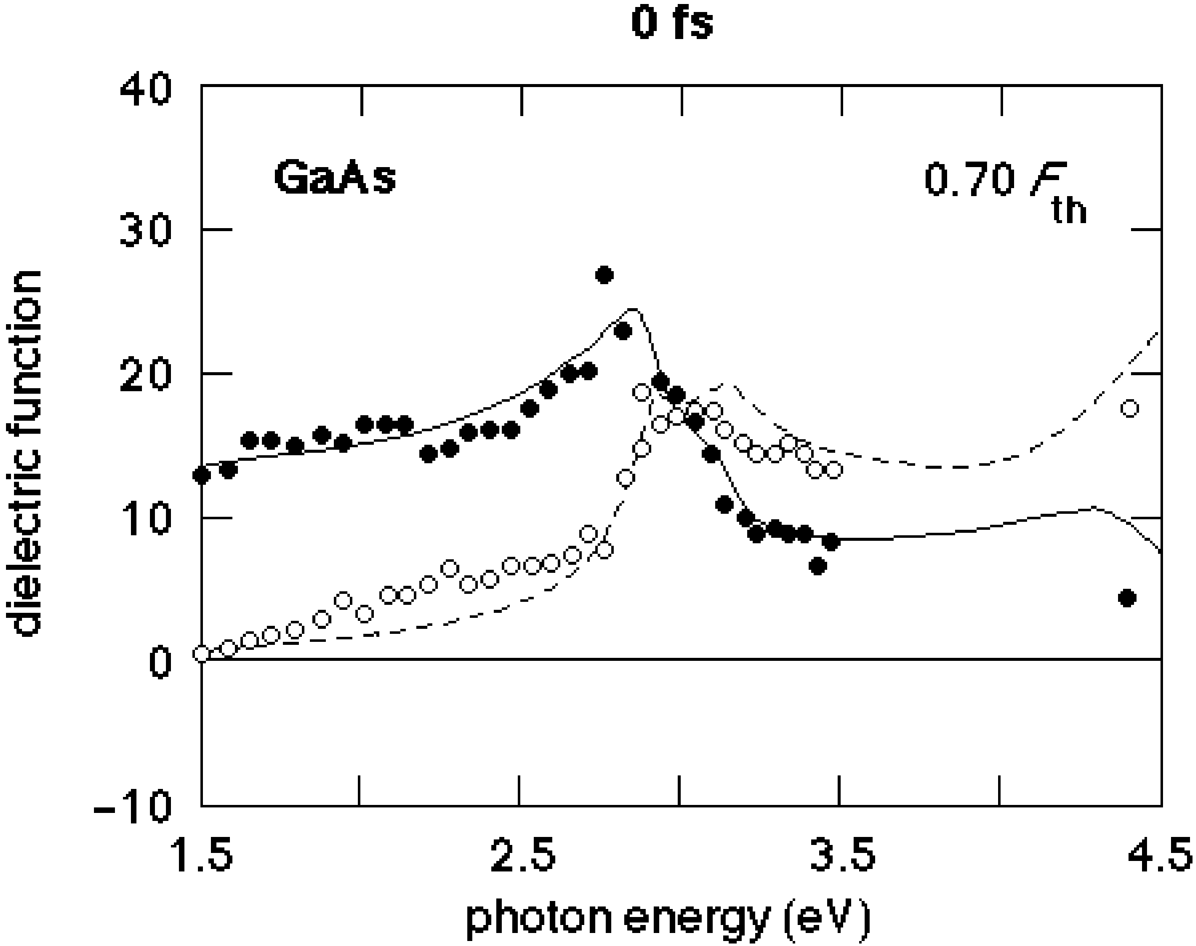

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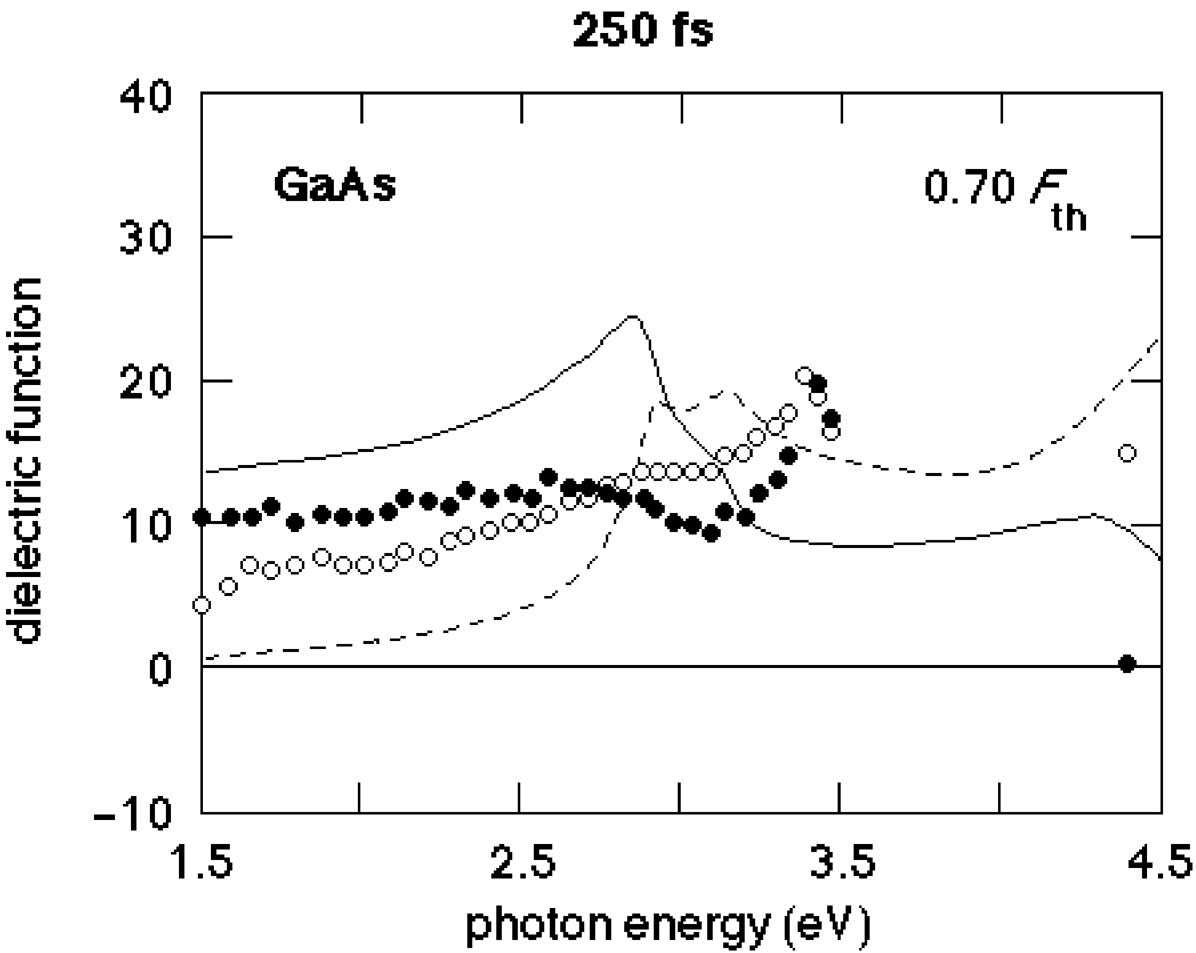

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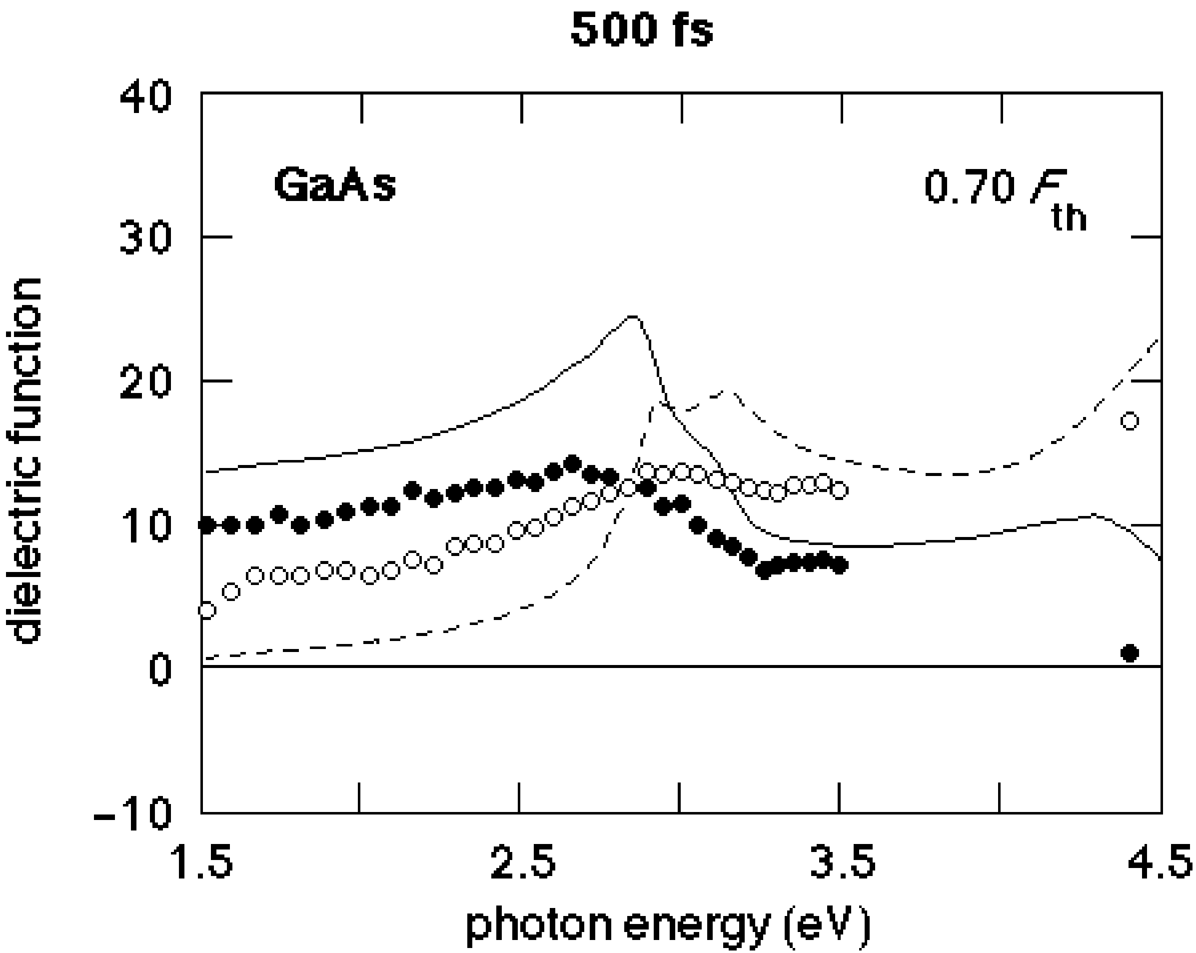

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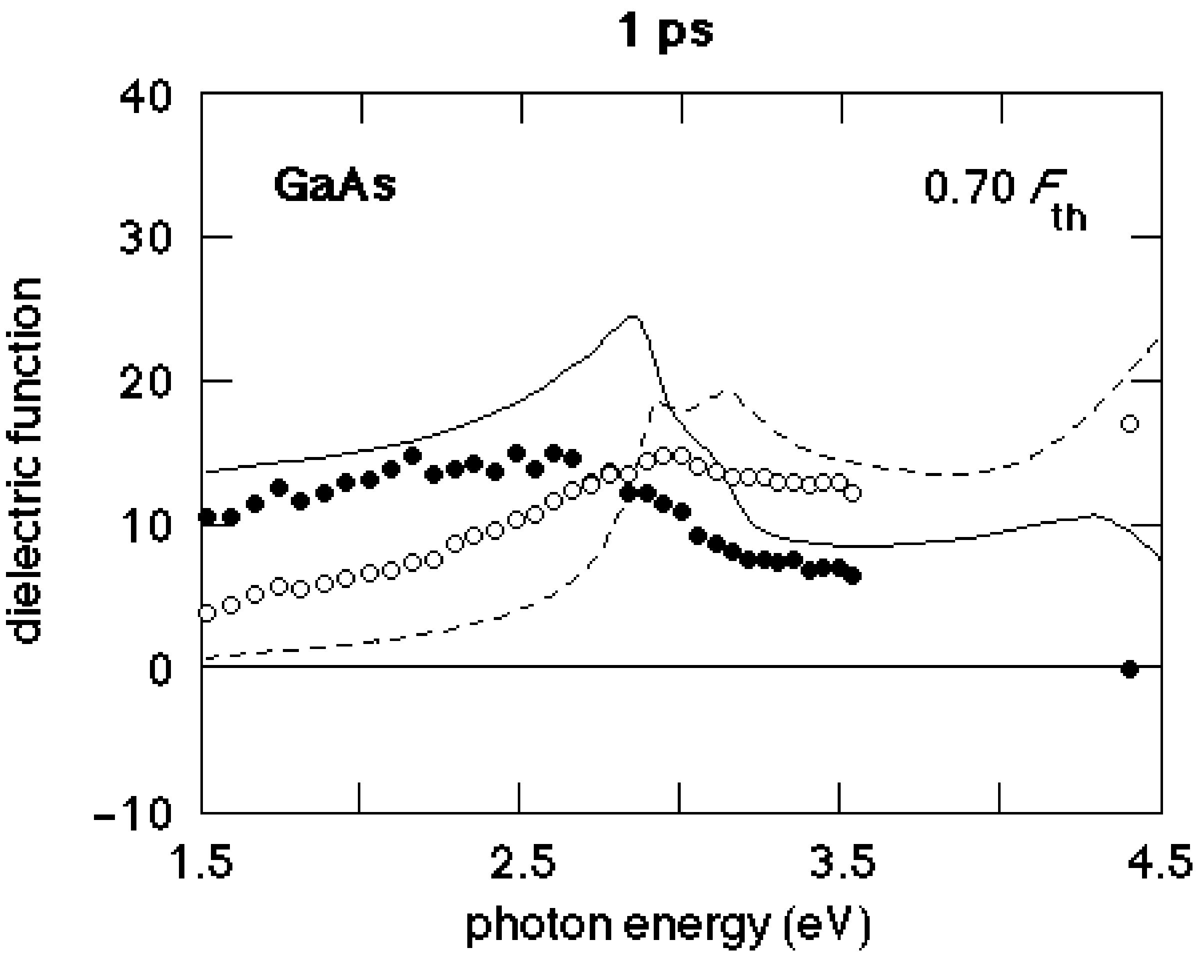

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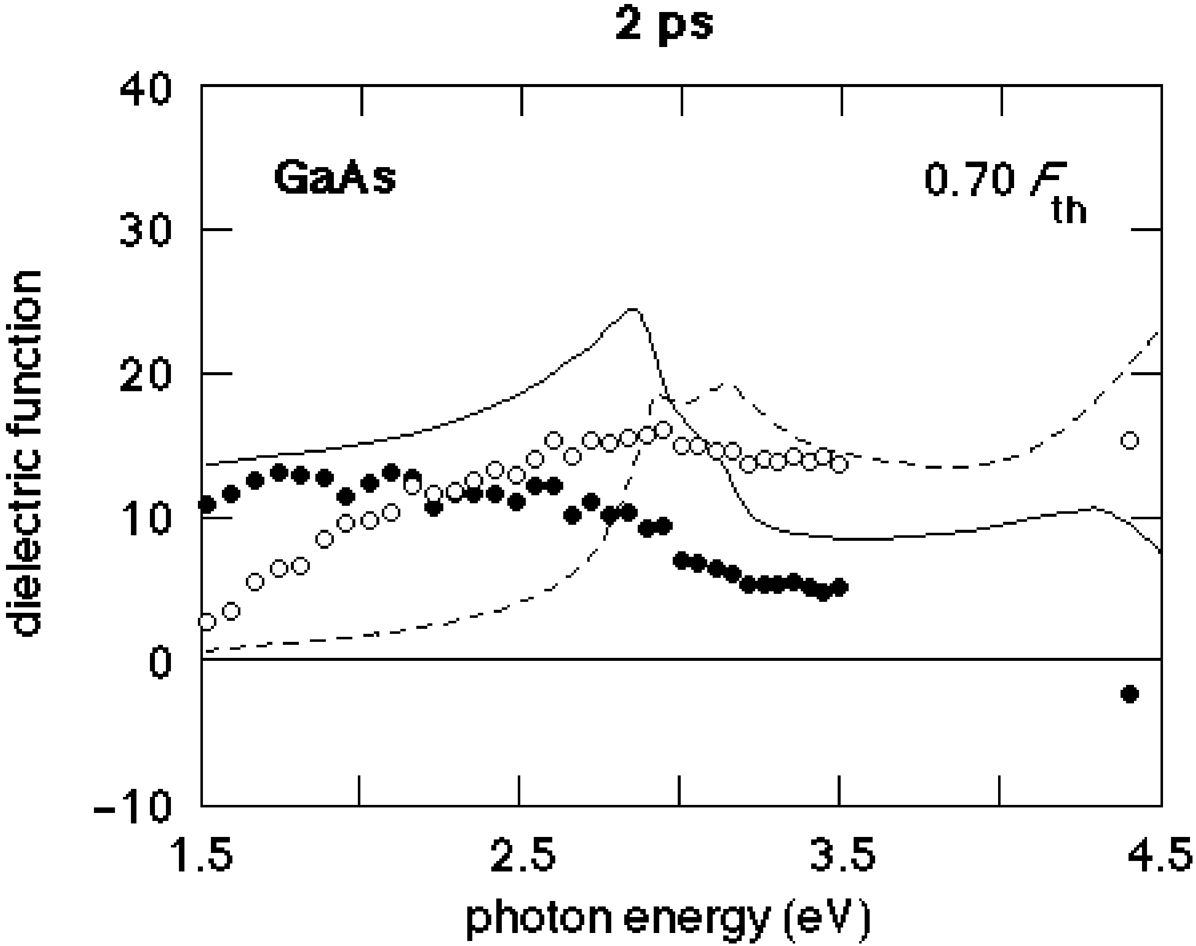

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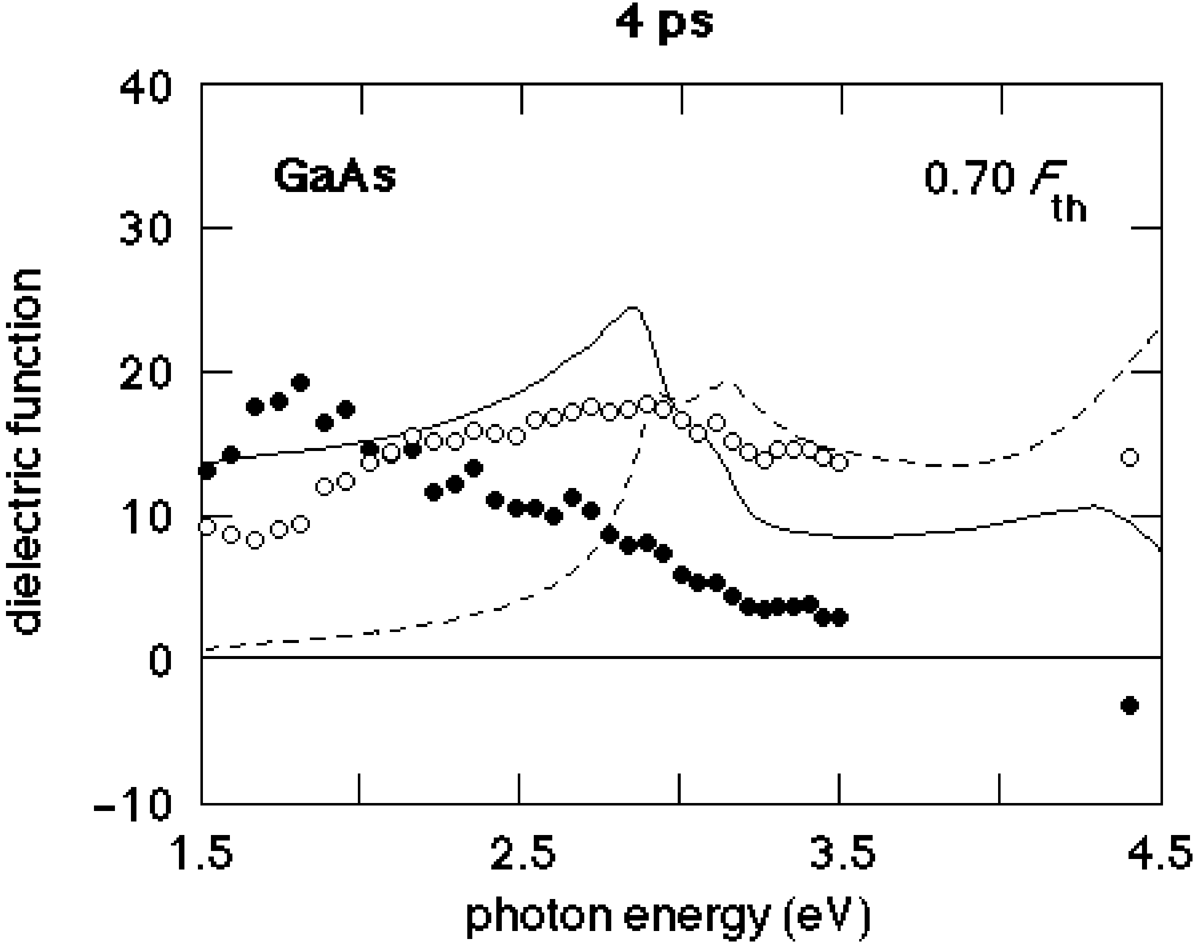

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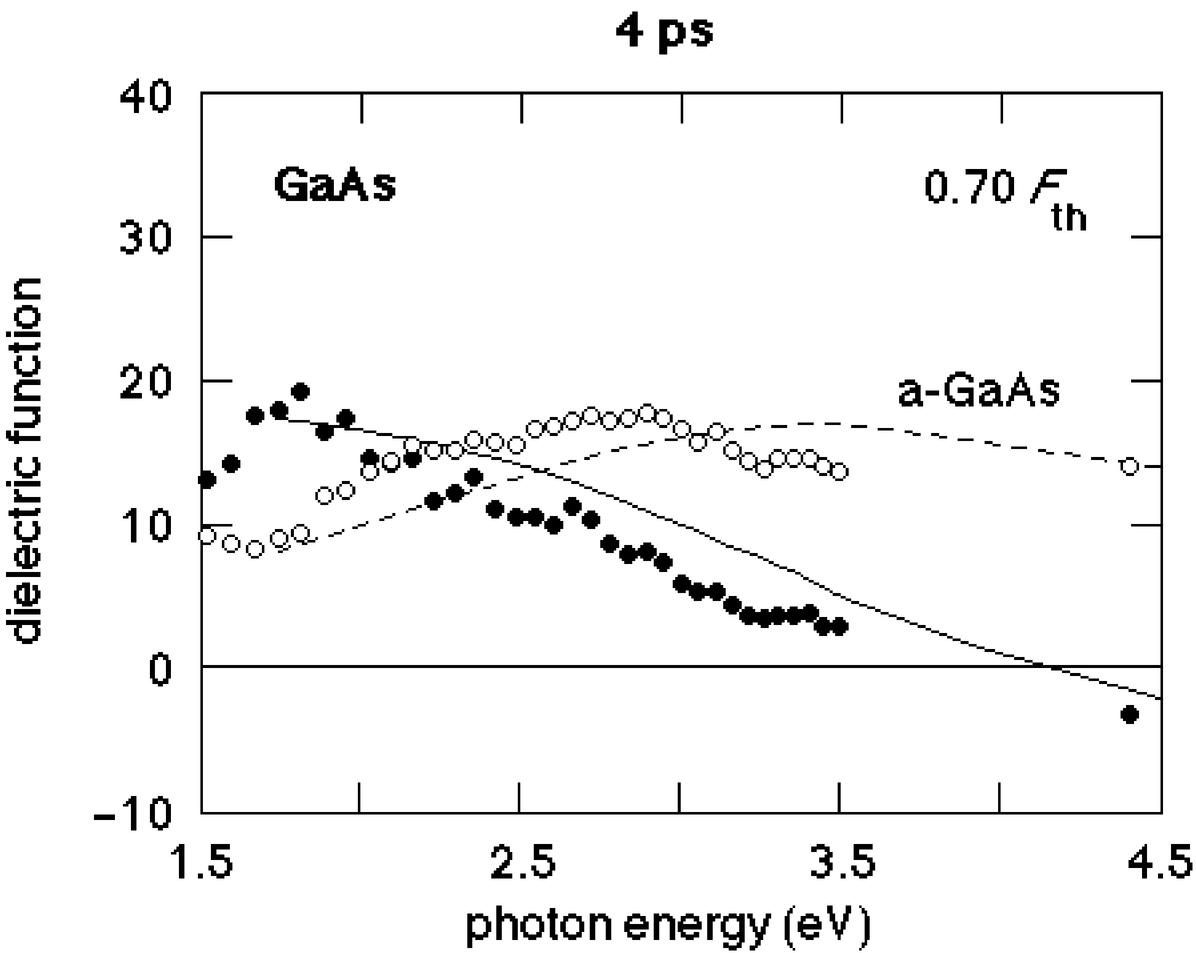

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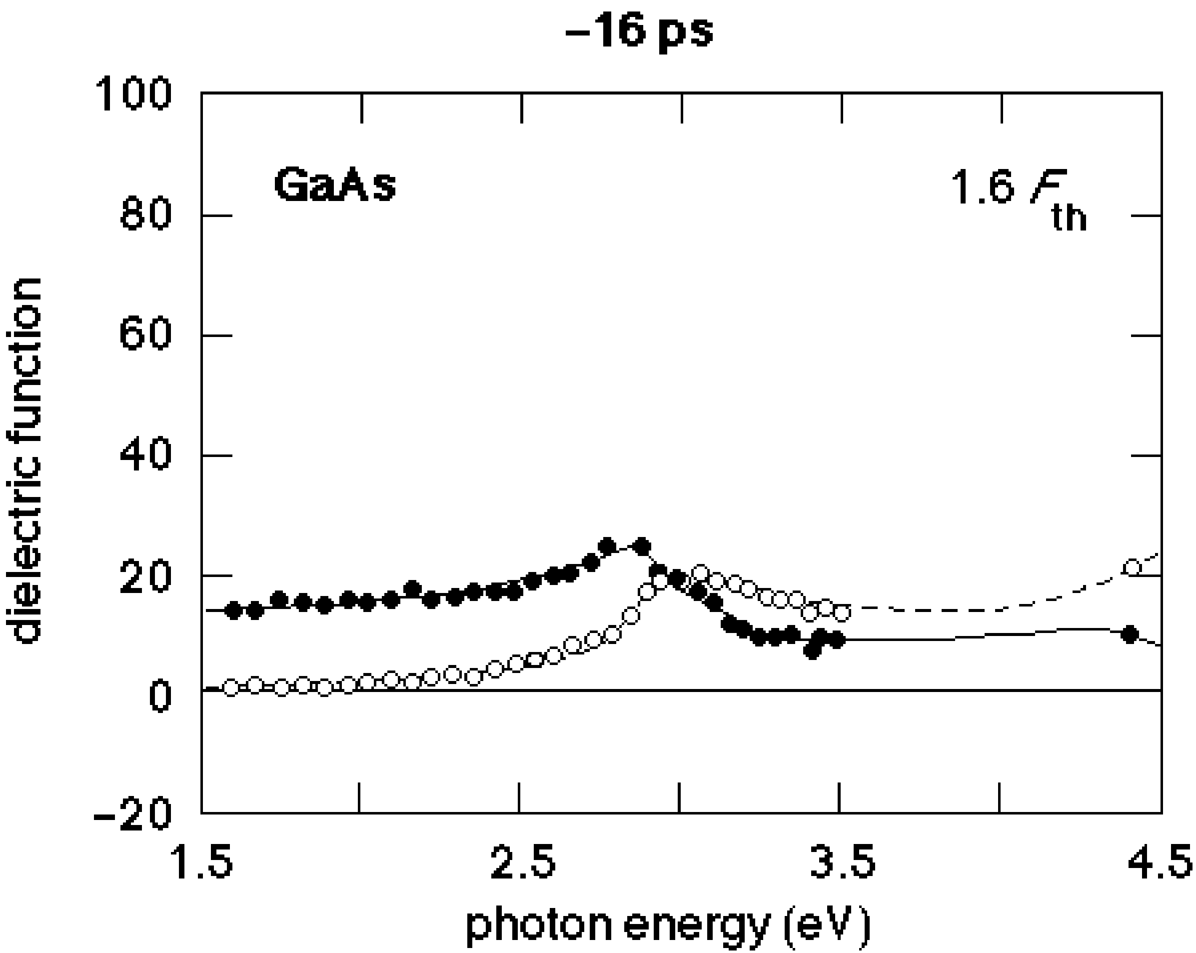
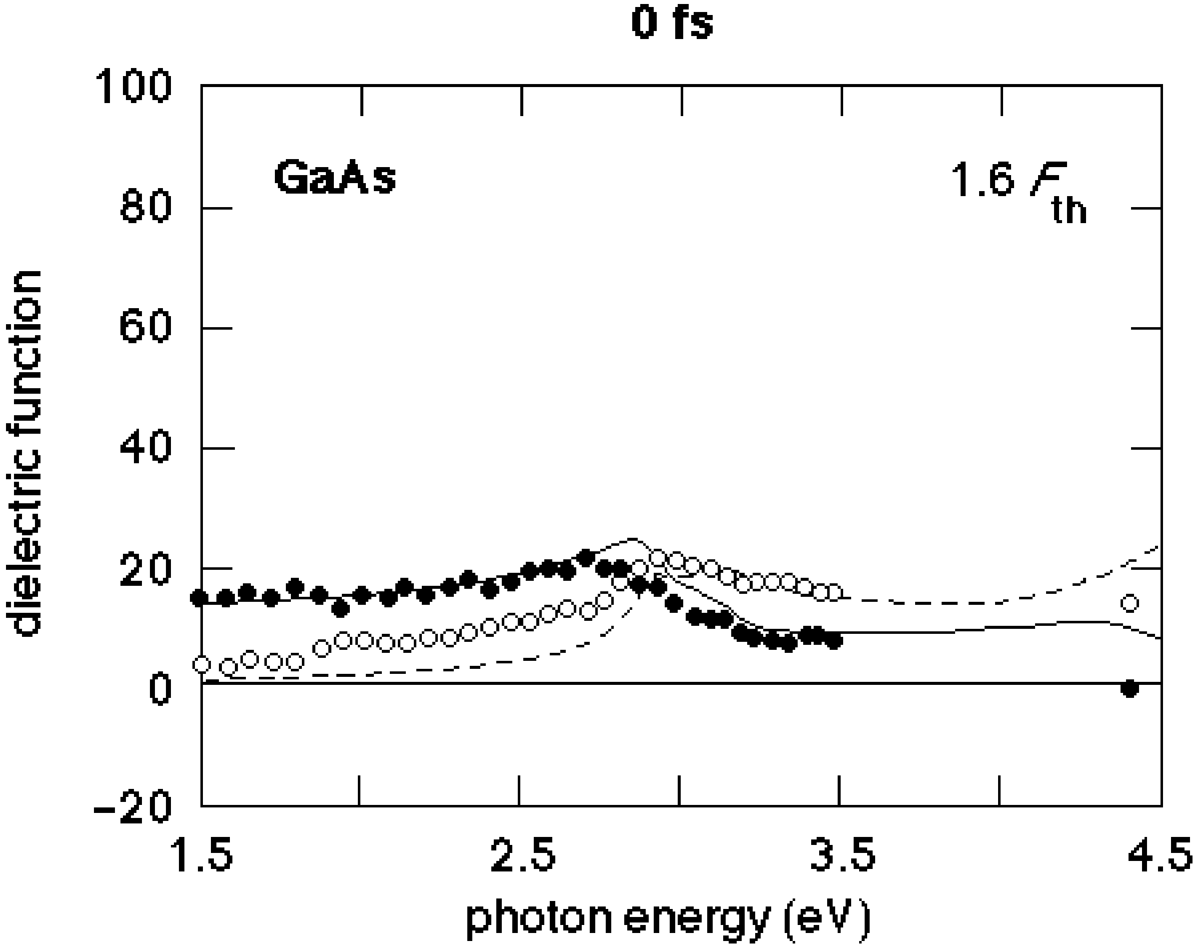


HIGH FLUENCE DATA



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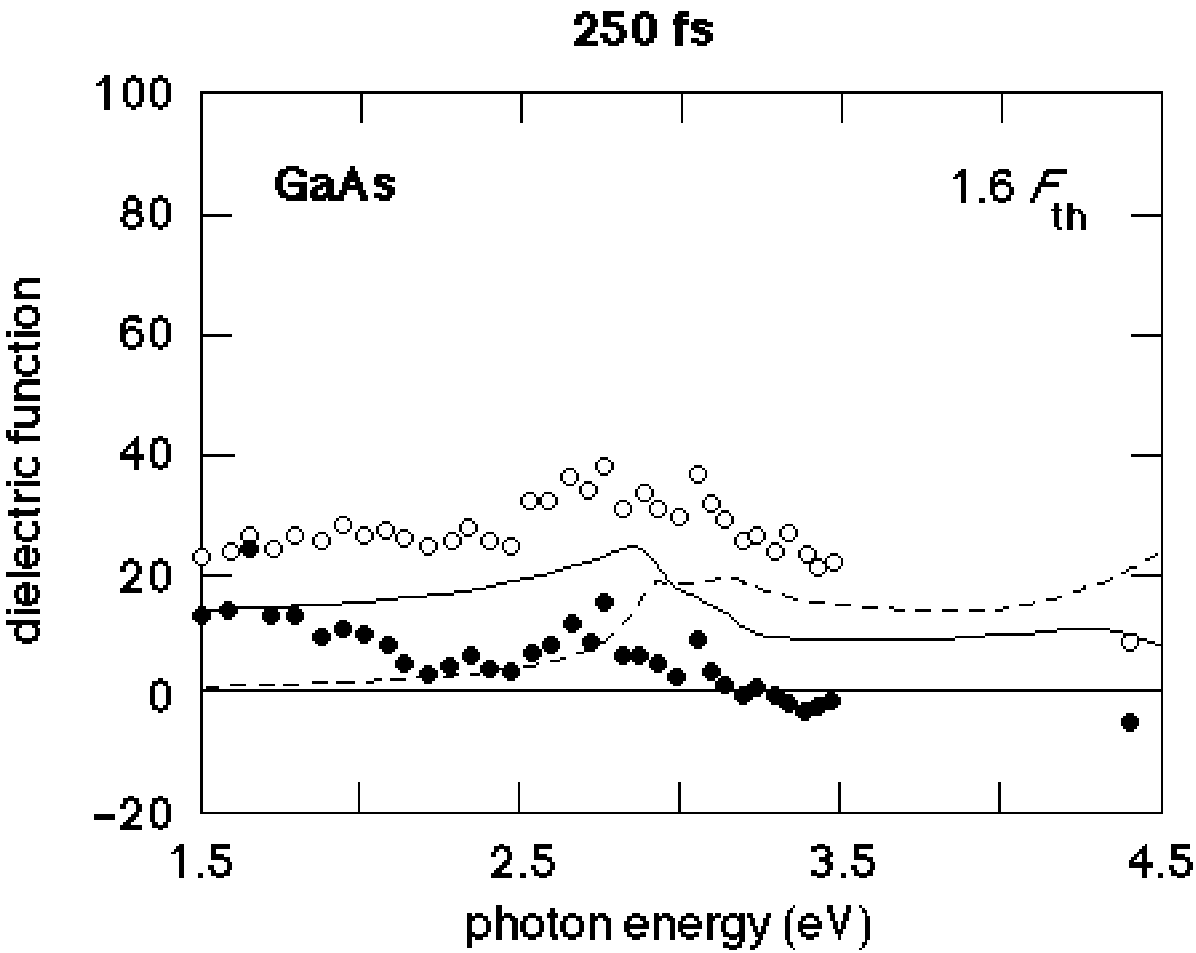

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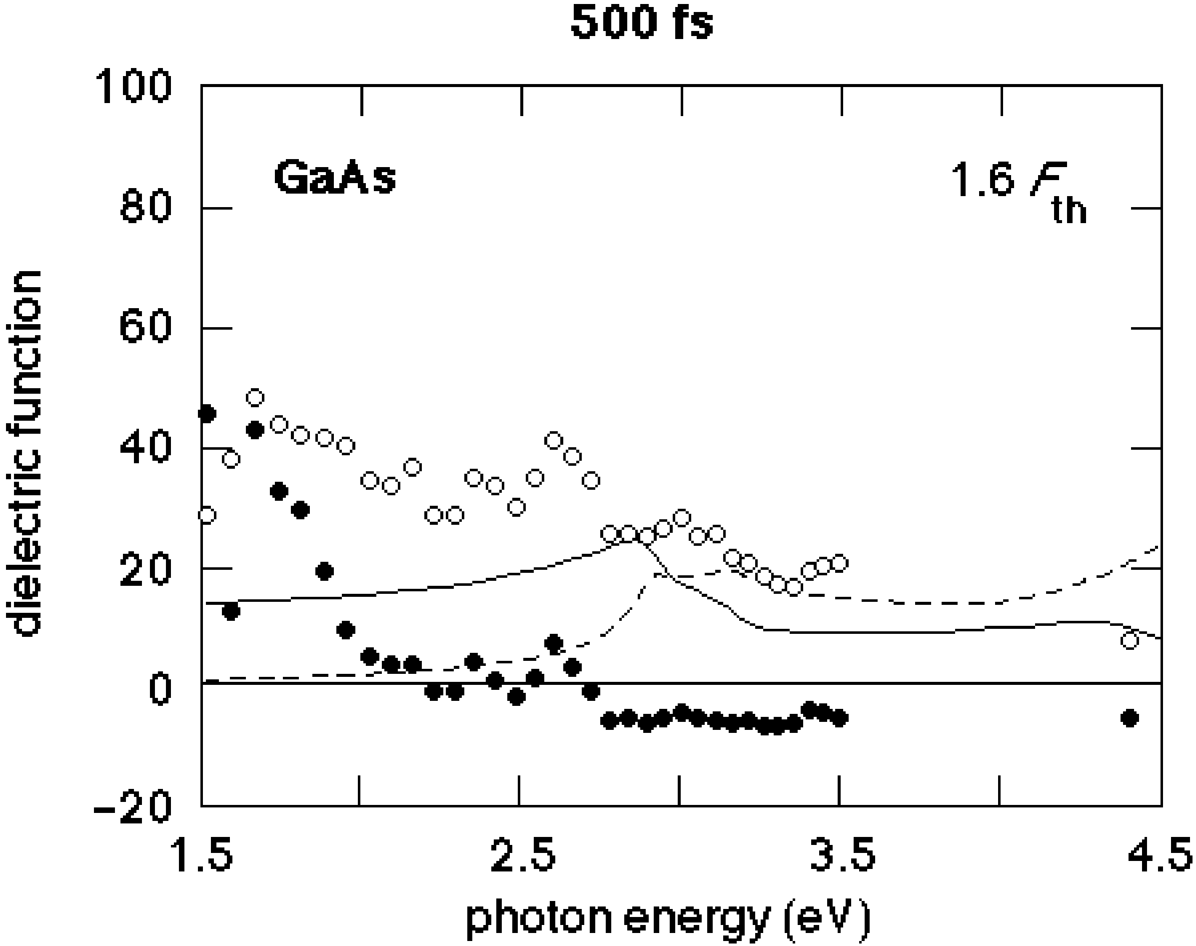

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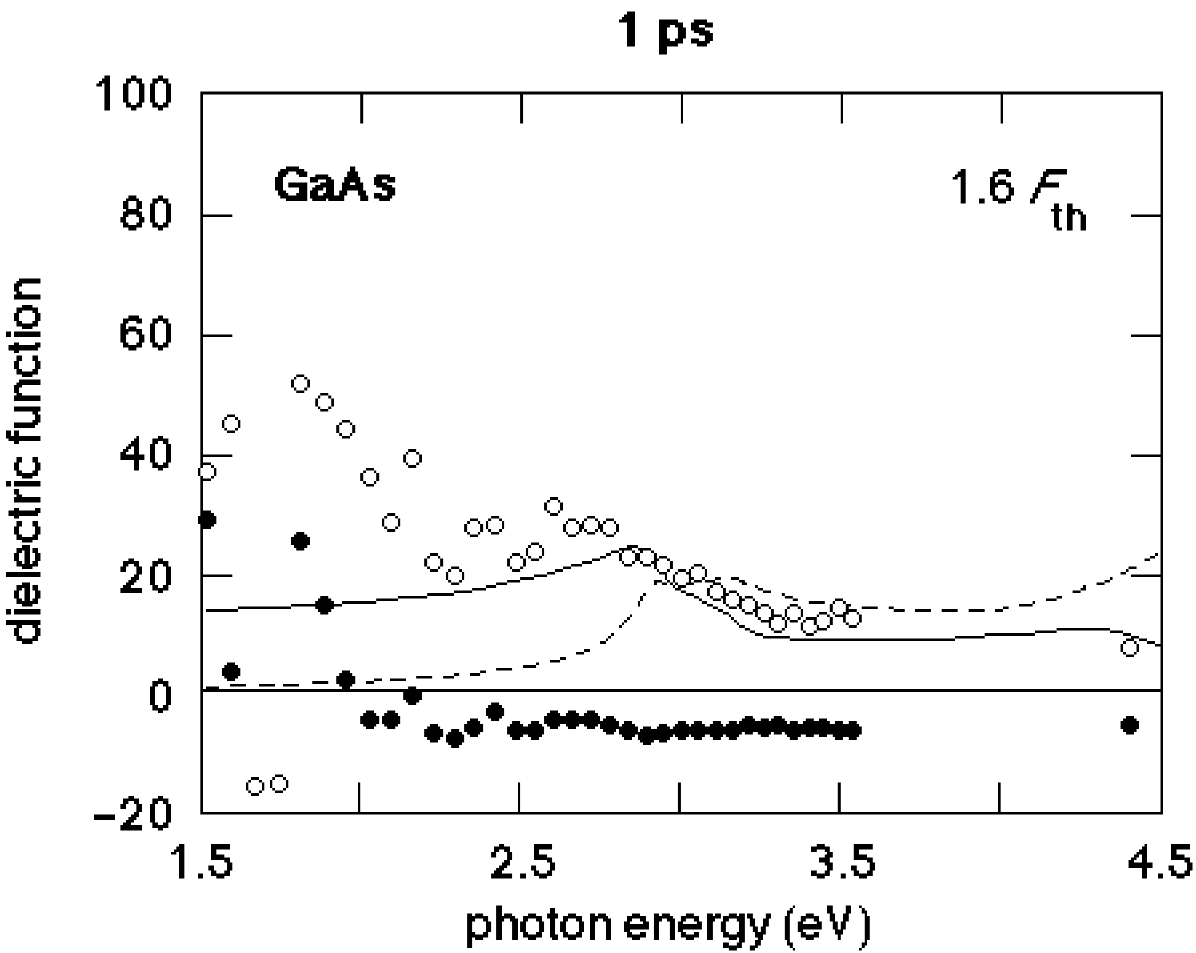

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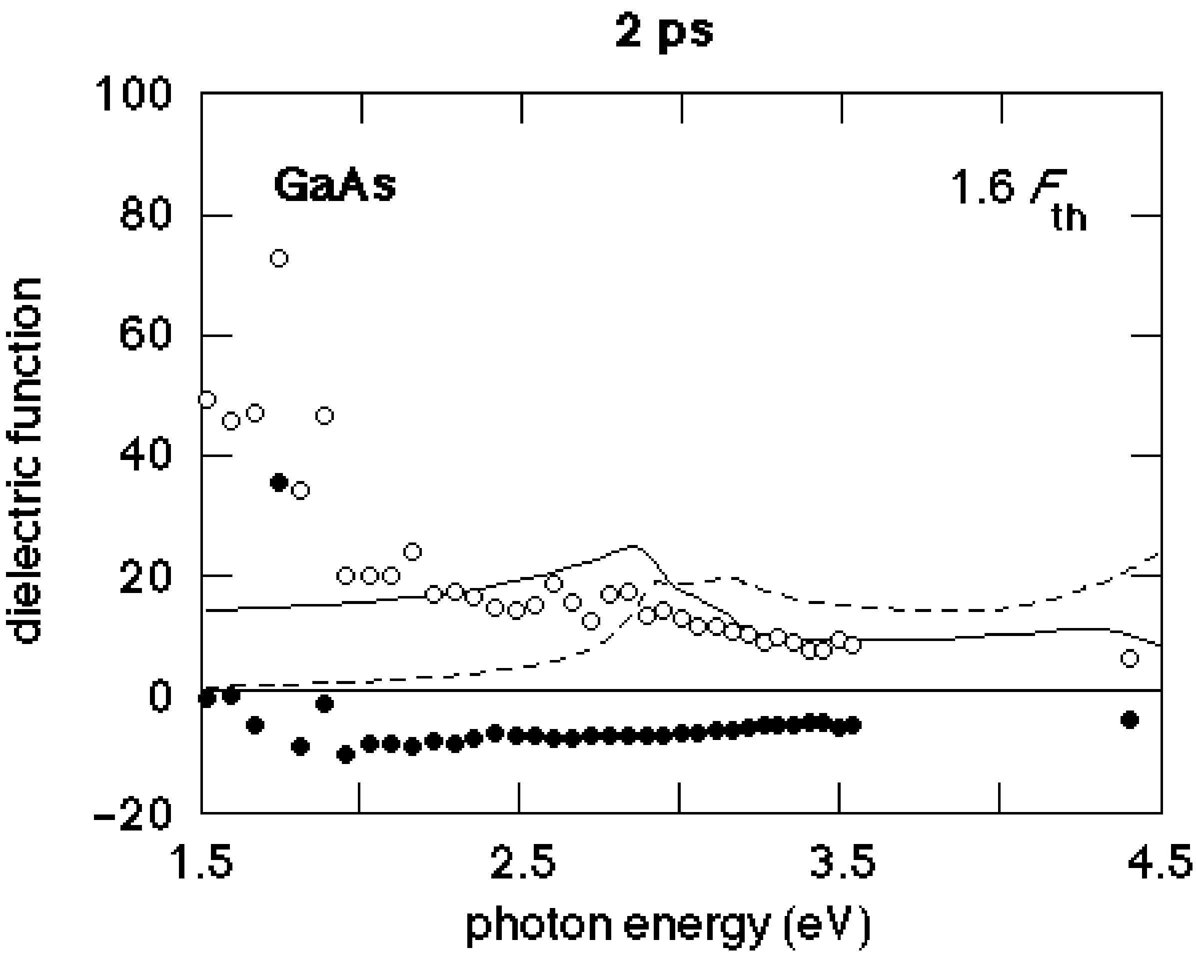
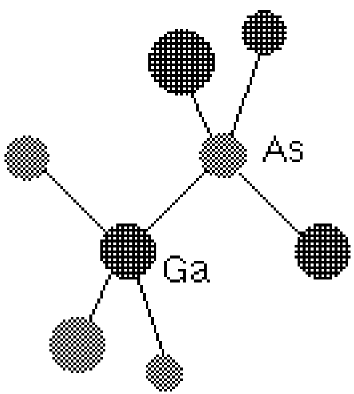
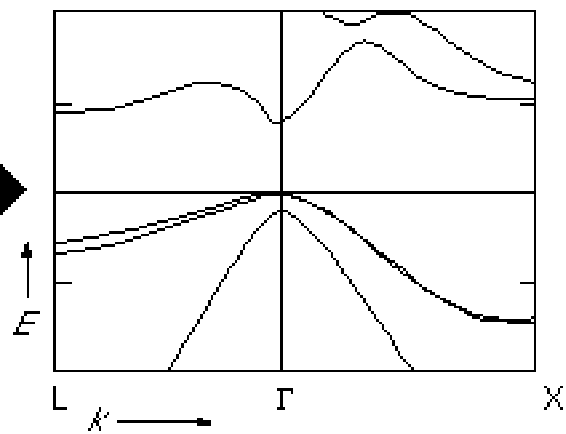


DISCUSSION

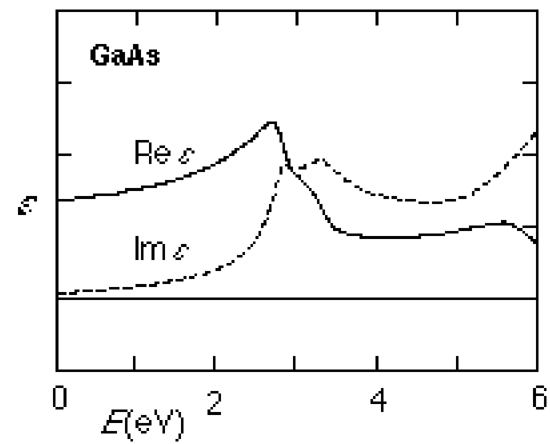
structure



bandstructure



dielectric function



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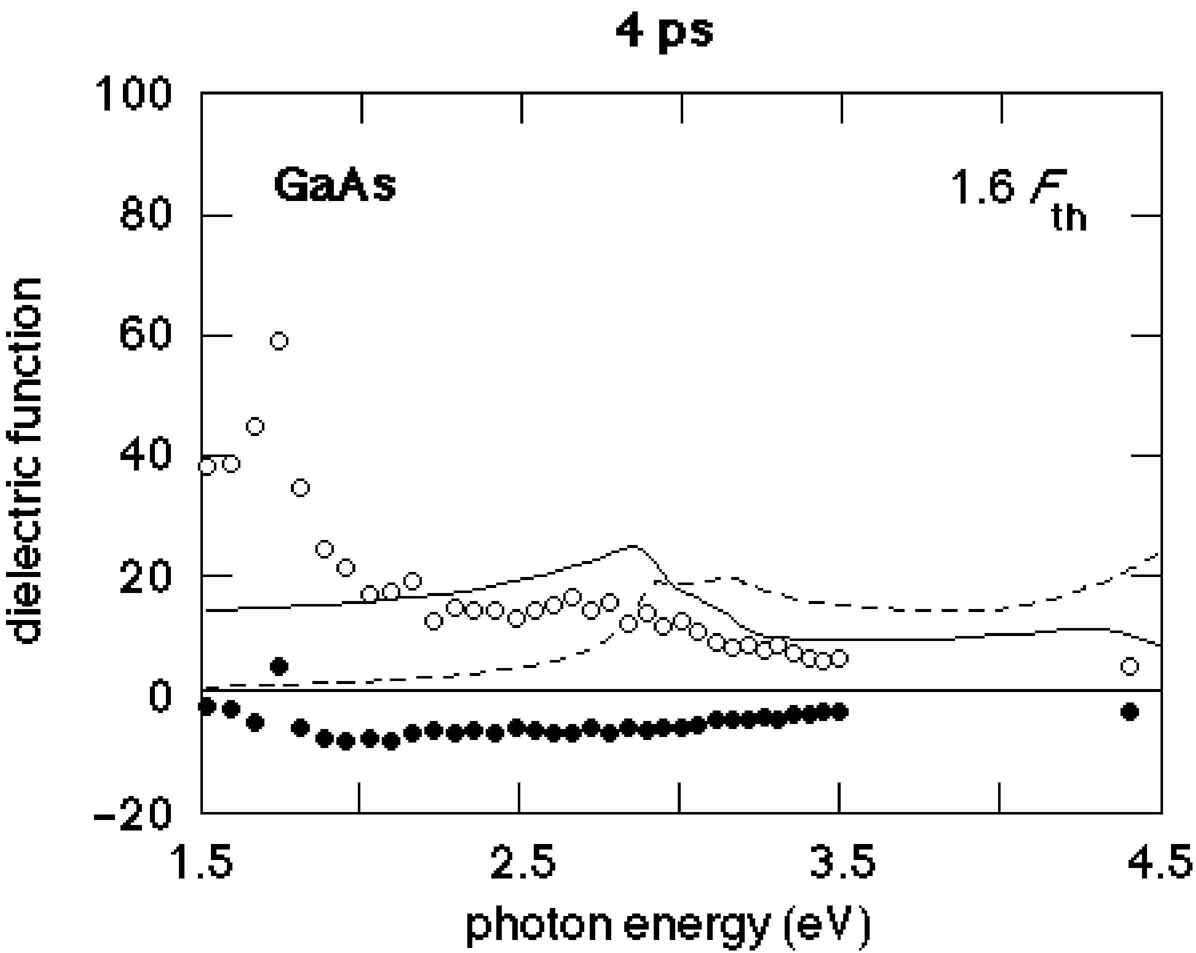

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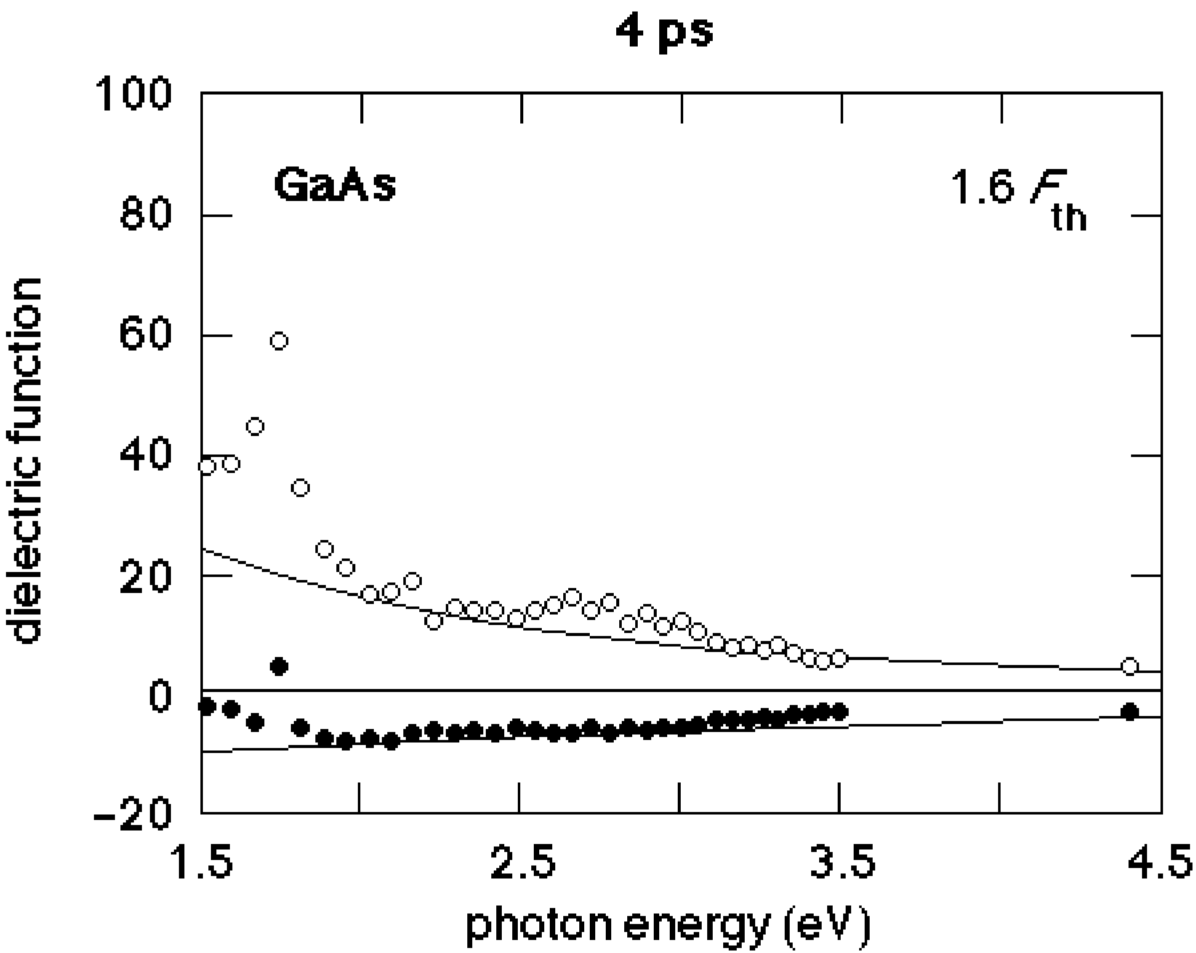

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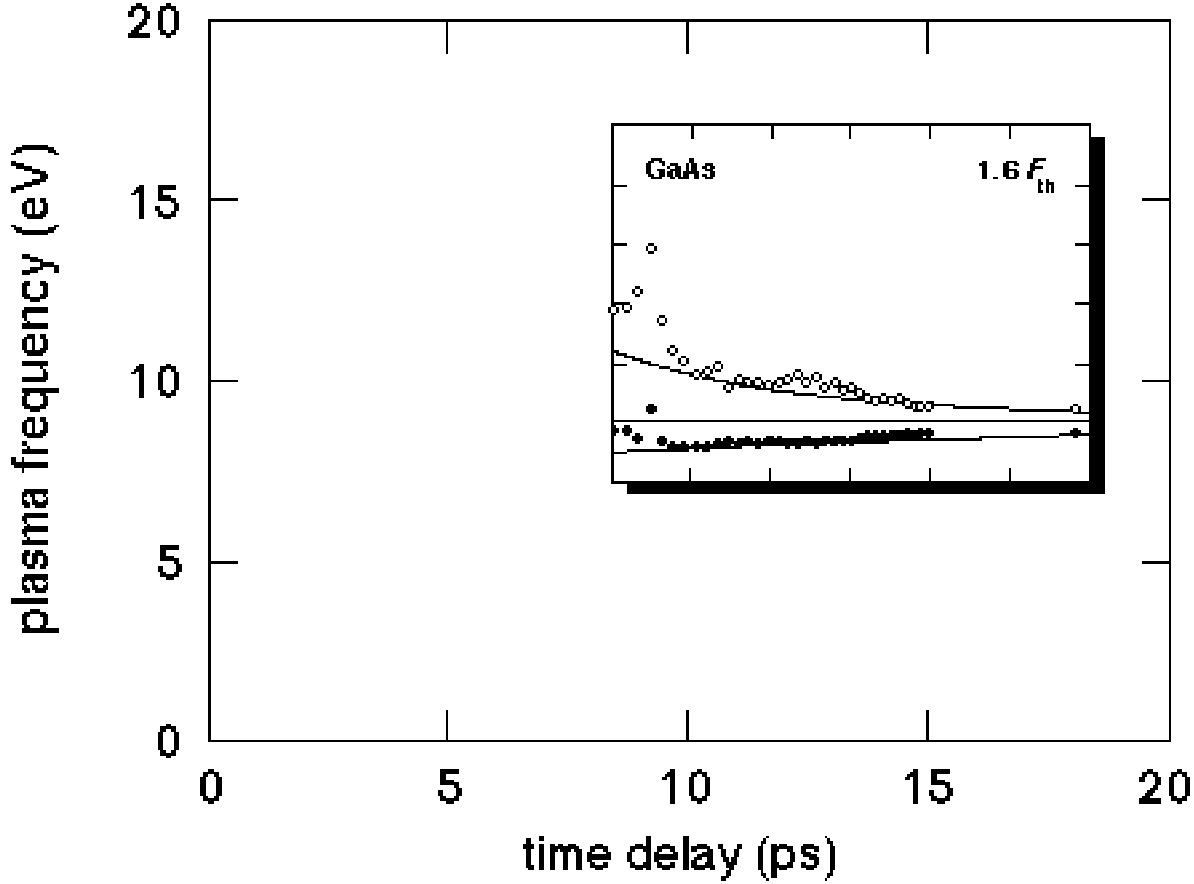

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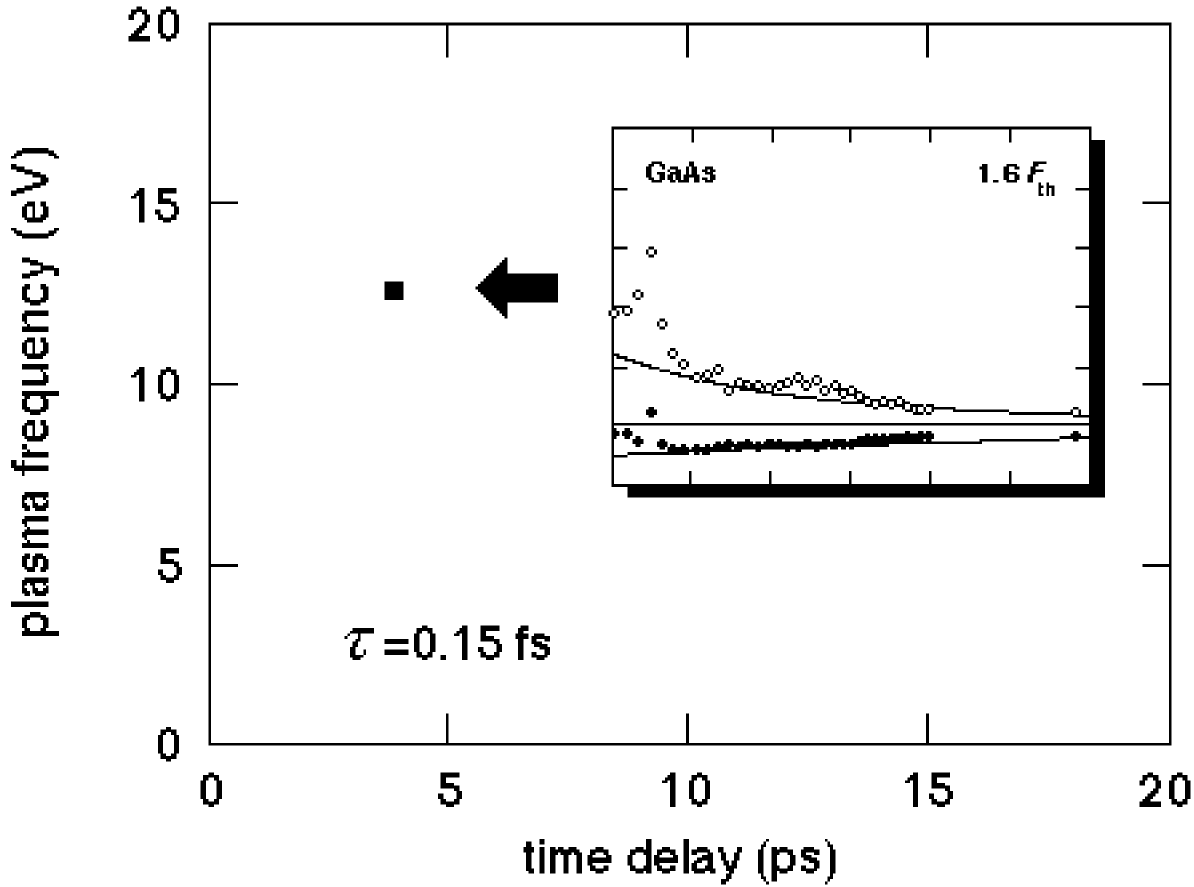

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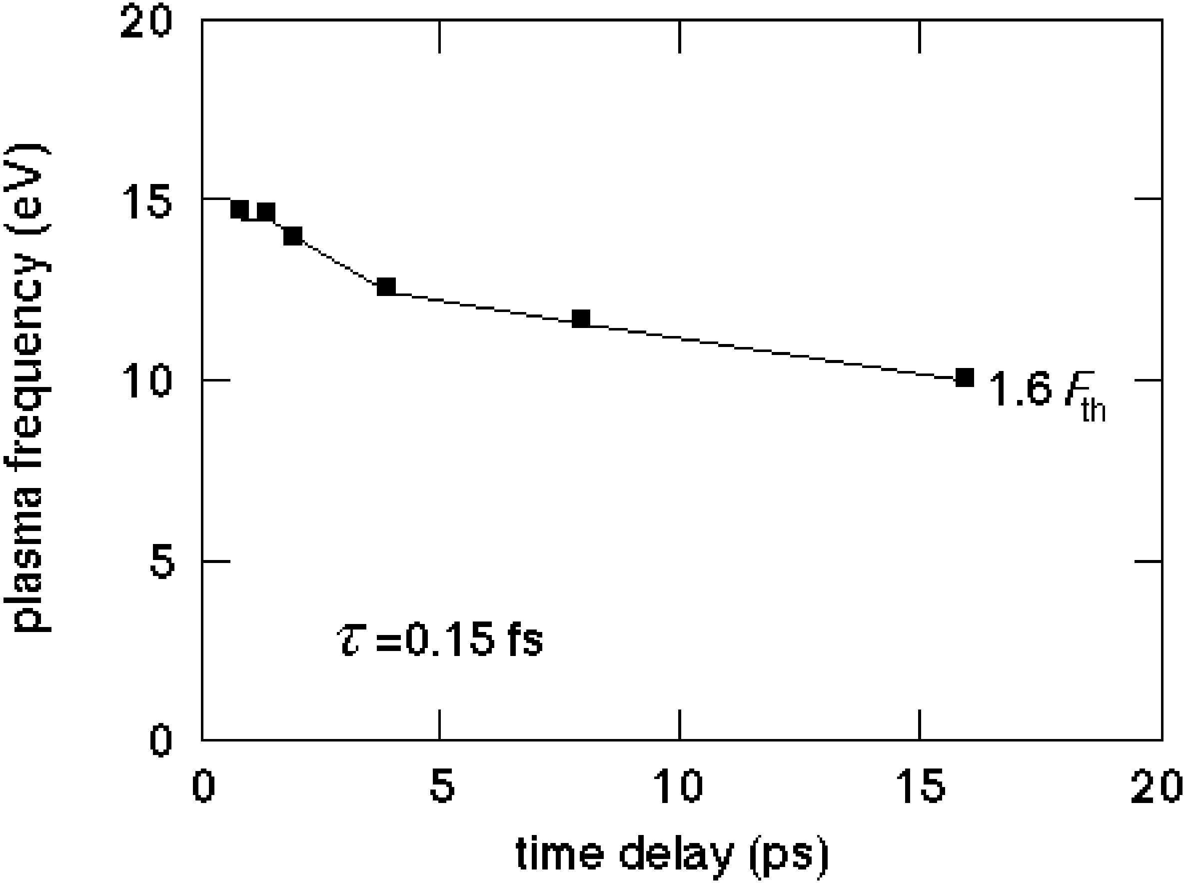

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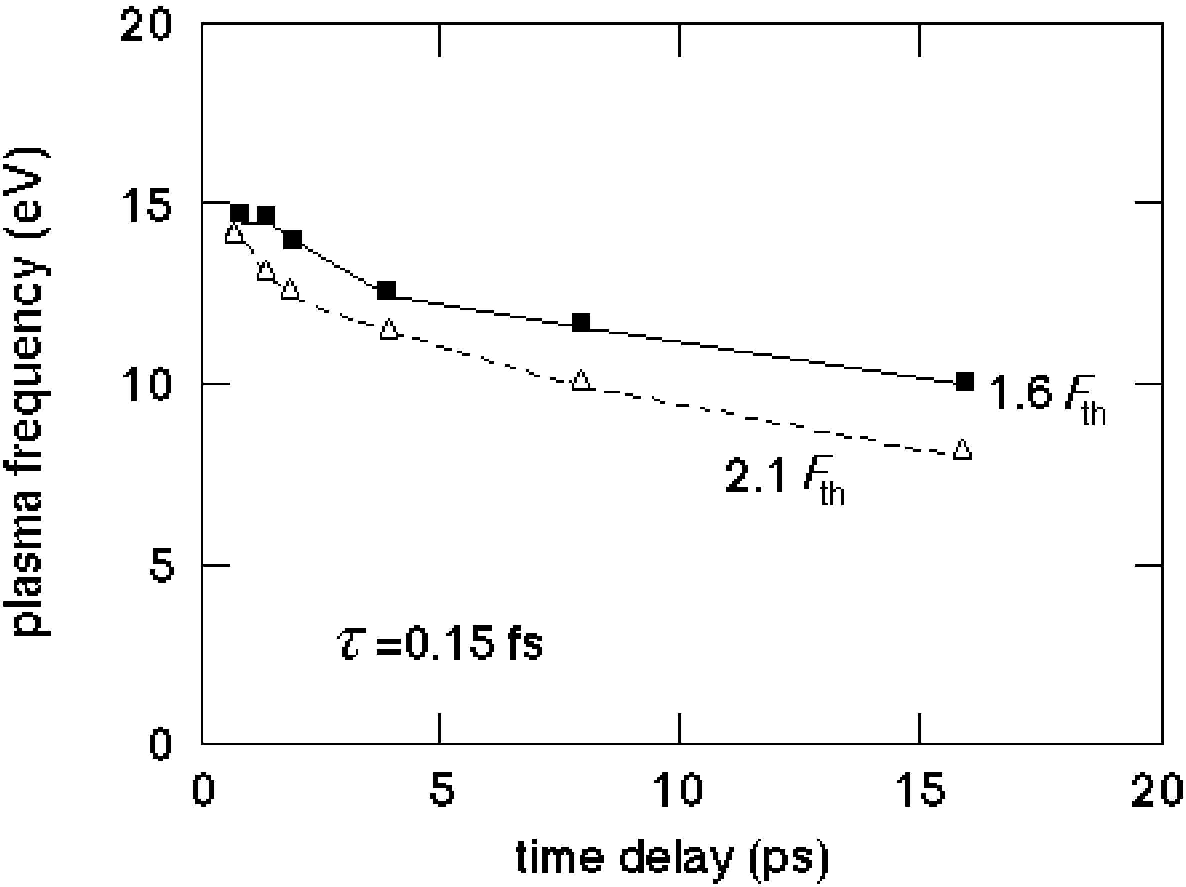

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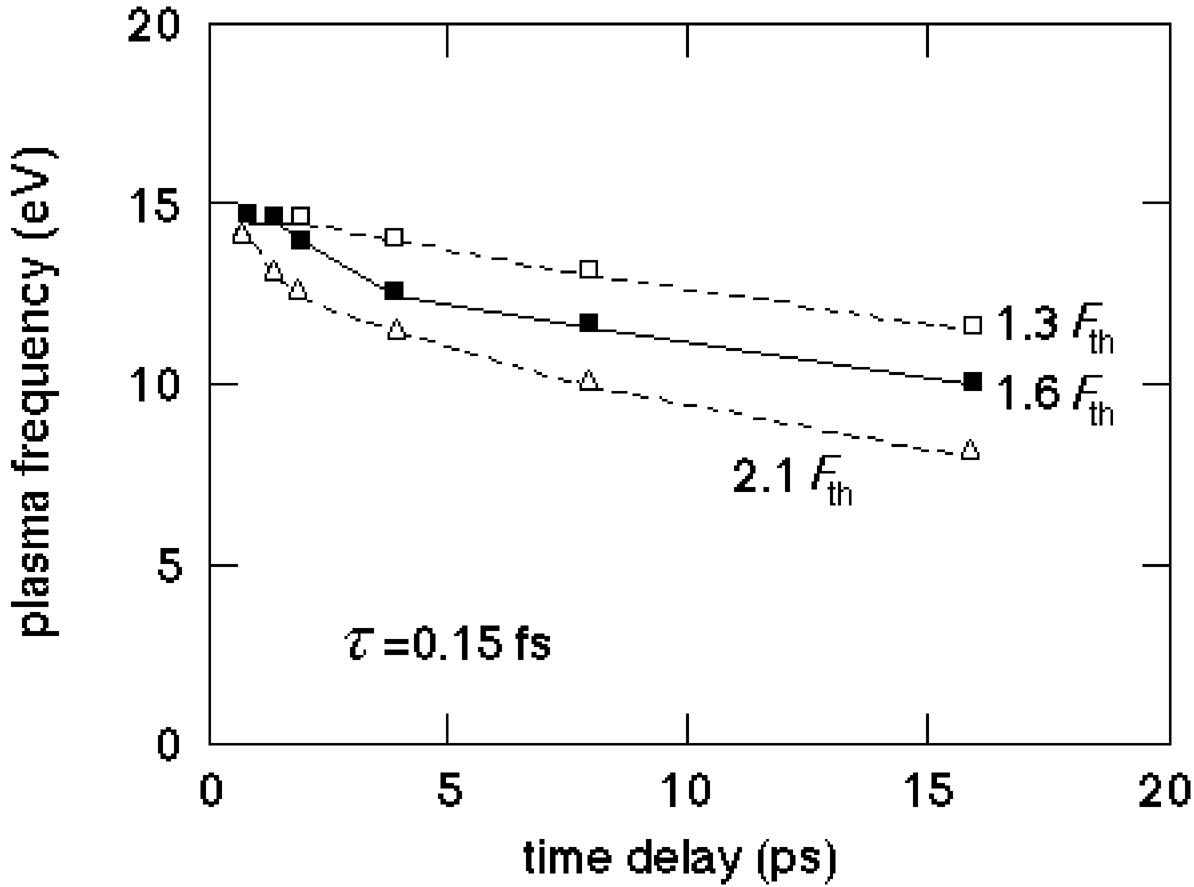

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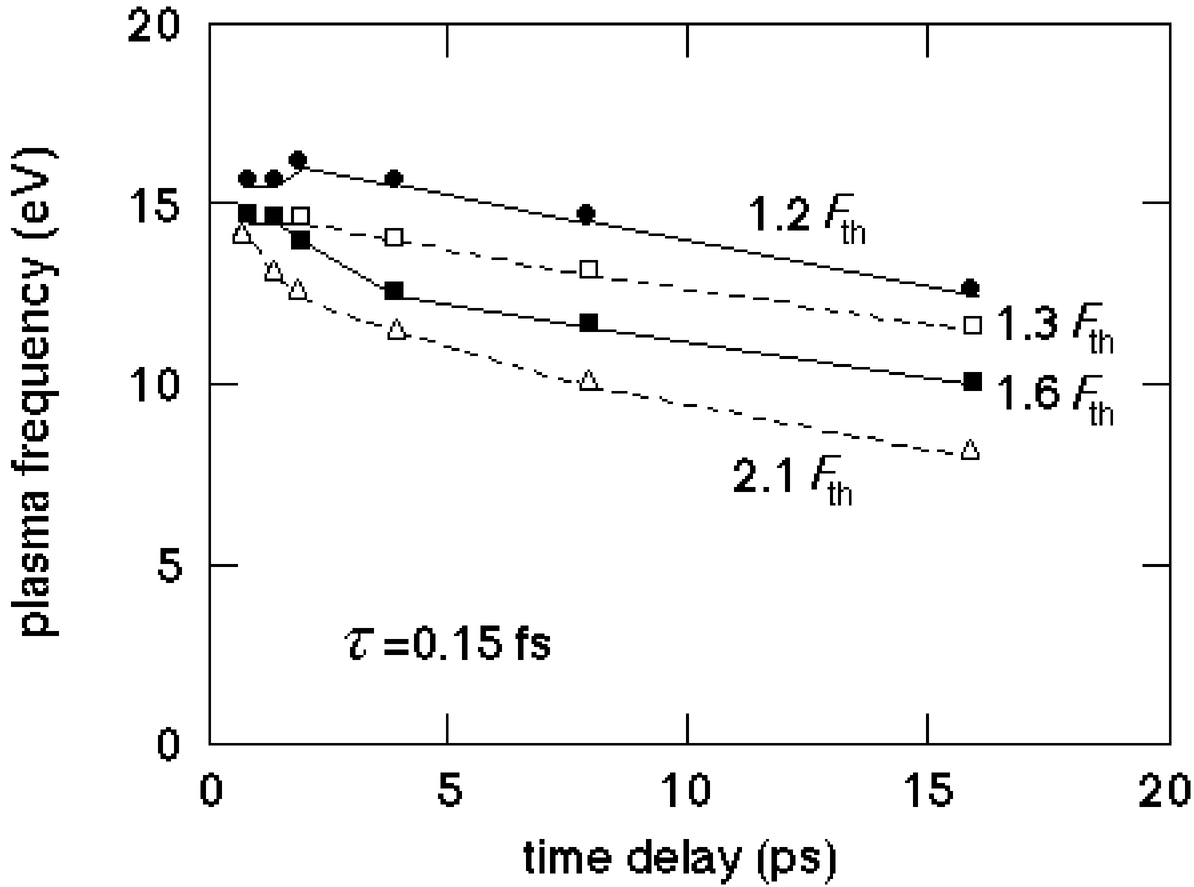

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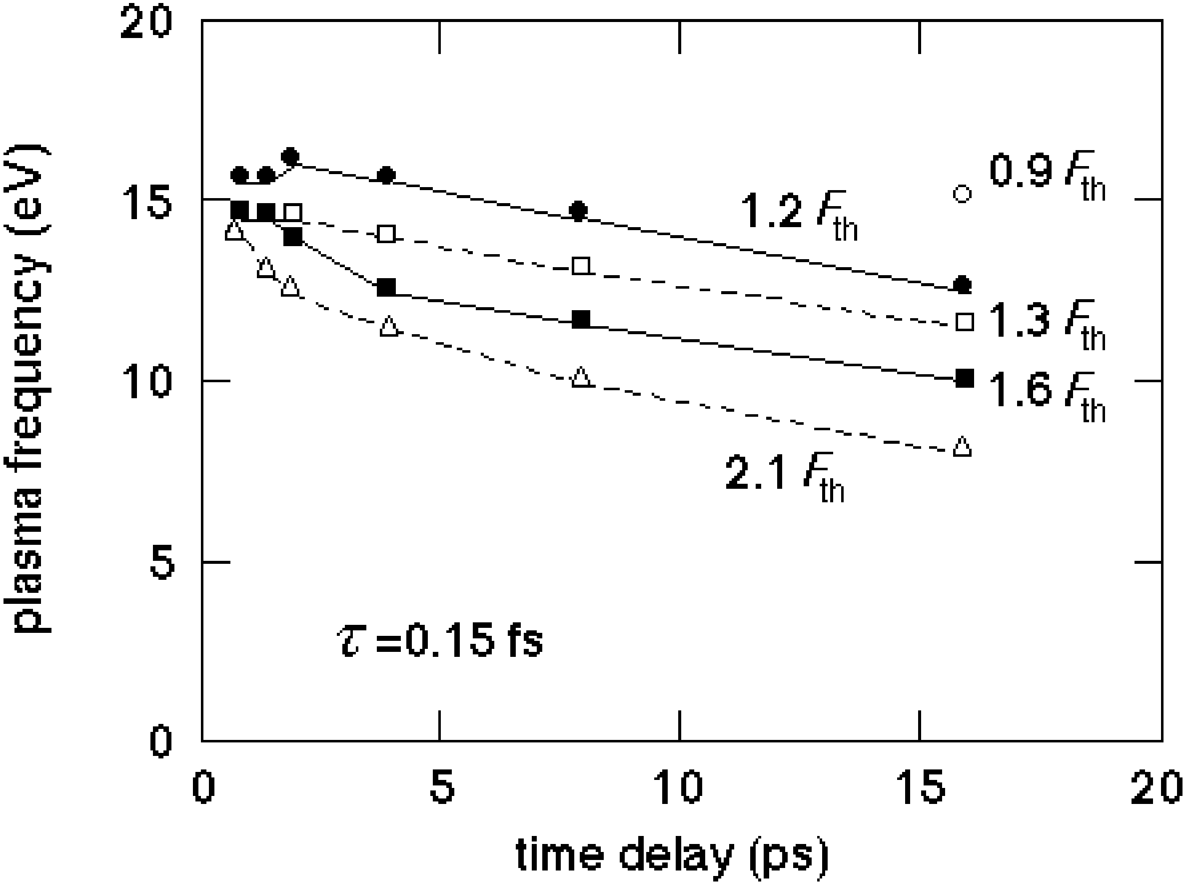
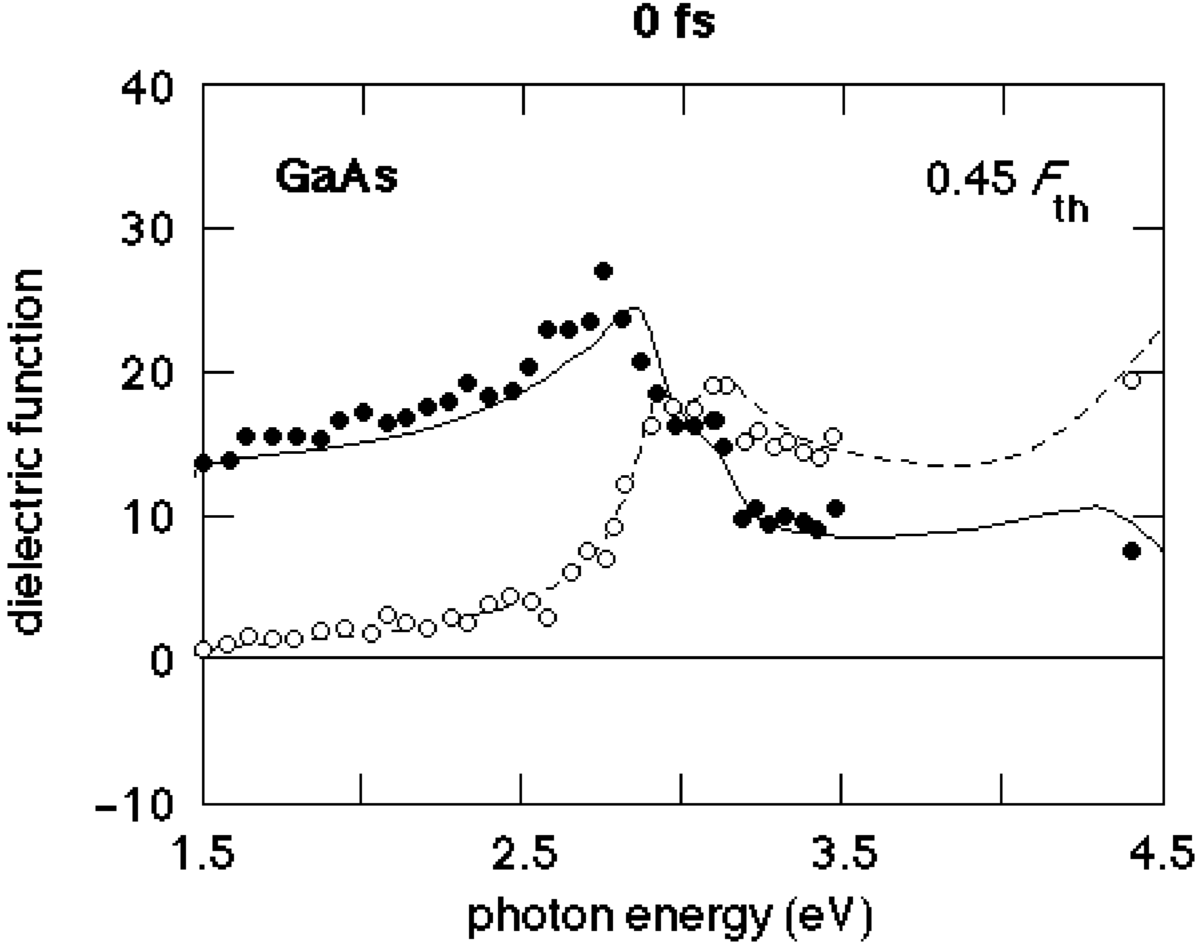
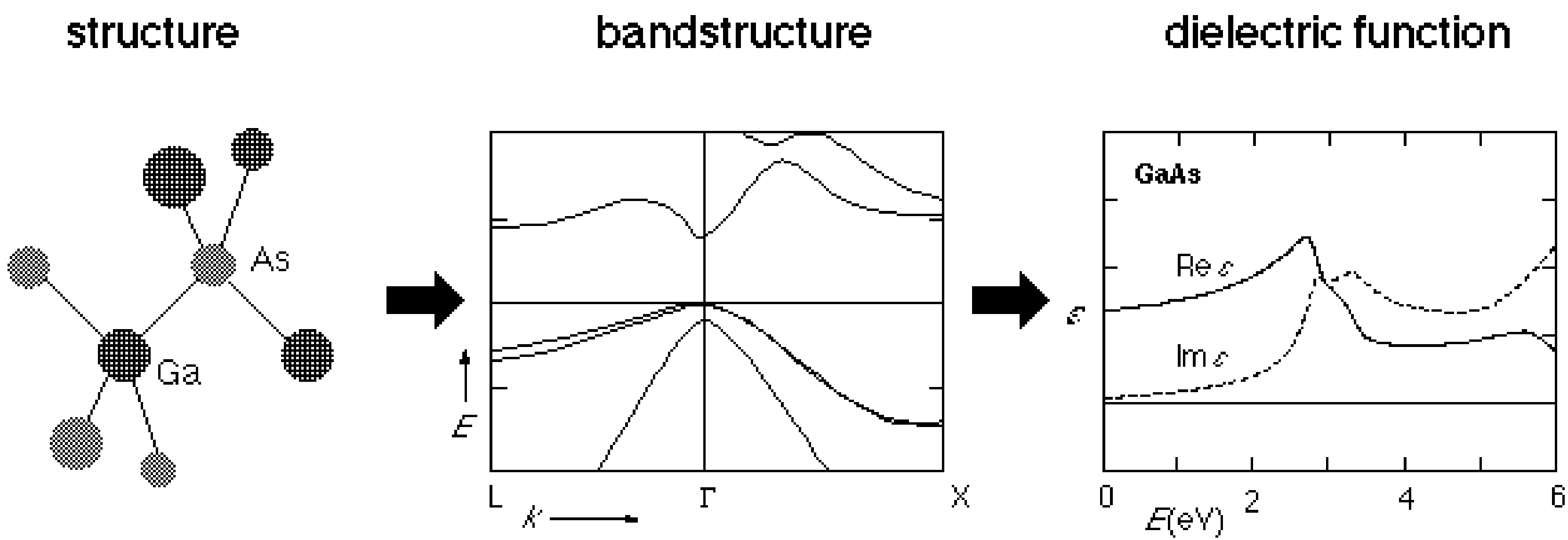


1. Method
2. Results
3. Discussion

LOW FLUENCE DATA



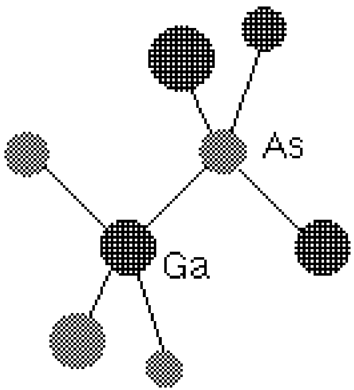
DISCUSSION



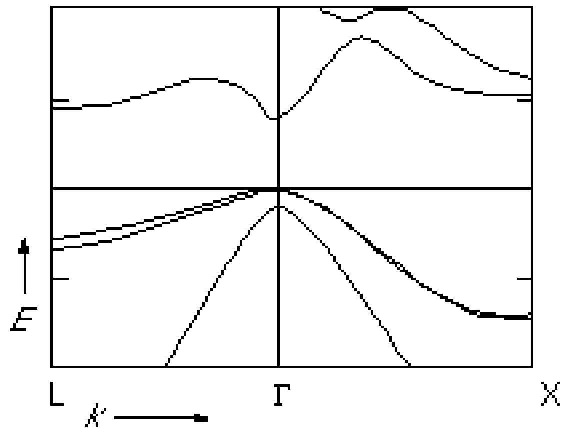
structure
bandstructure
dielectric function
As
Ga
E
L
k
Γ
X
GaAs
Re ε
Im ε
ε
0
2
4
6
E(eV)

SHORT TIME SCALE (≈0.5 ps)

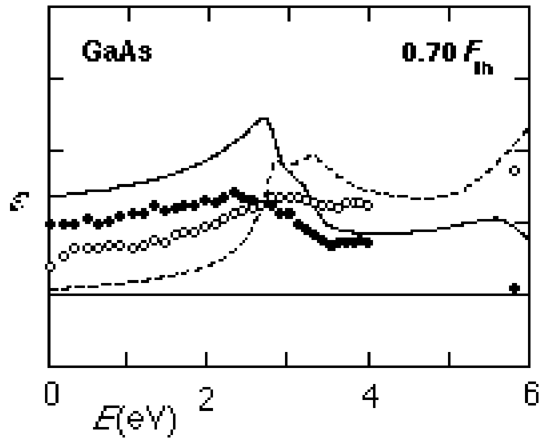
structure



bandstructure

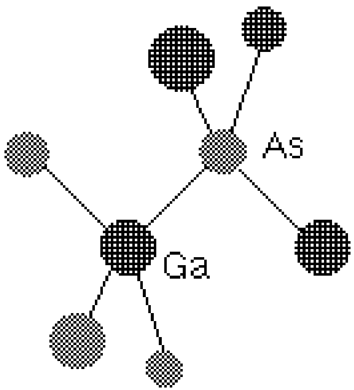


dielectric function

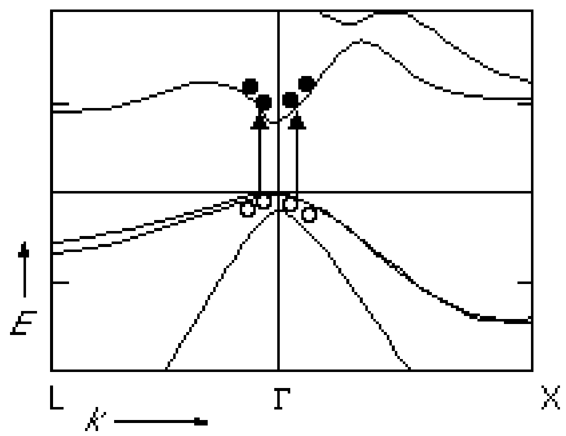


SHORT TIME SCALE (≈0.5 ps)

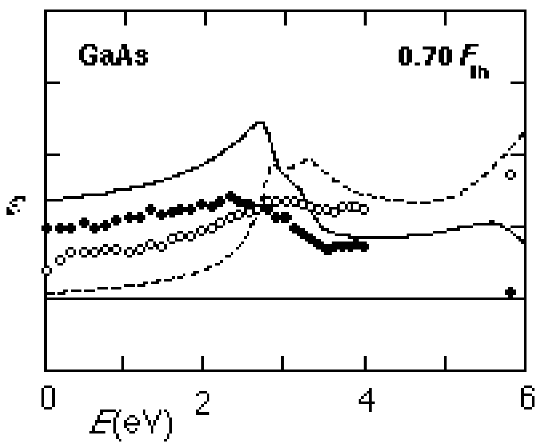
structure



bandstructure

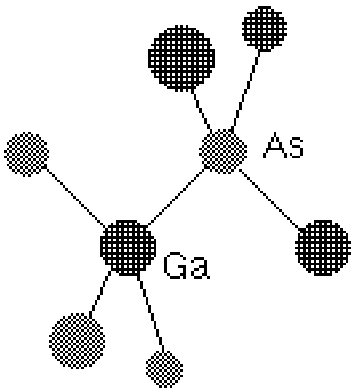


dielectric function

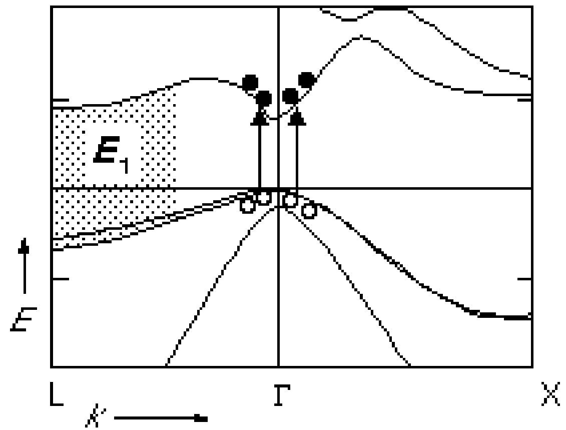


SHORT TIME SCALE (≈0.5 ps)

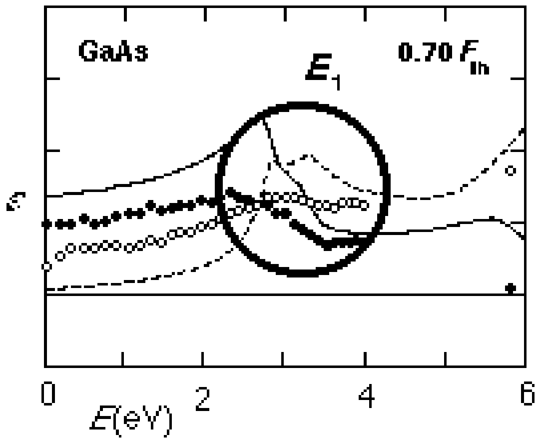
structure



bandstructure

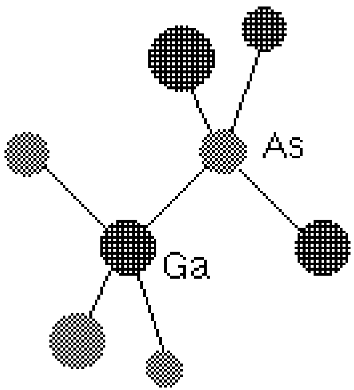


dielectric function

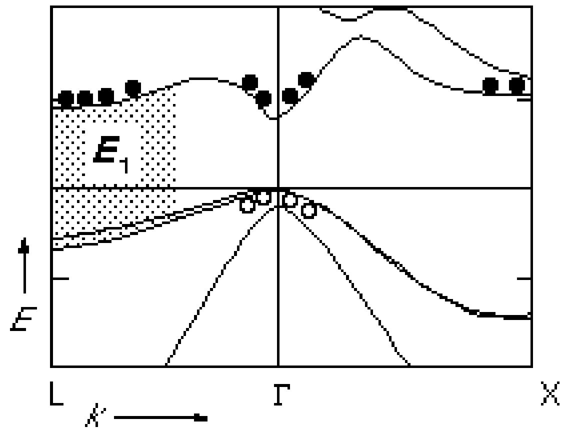


SHORT TIME SCALE (≈0.5 ps)

structure



bandstructure



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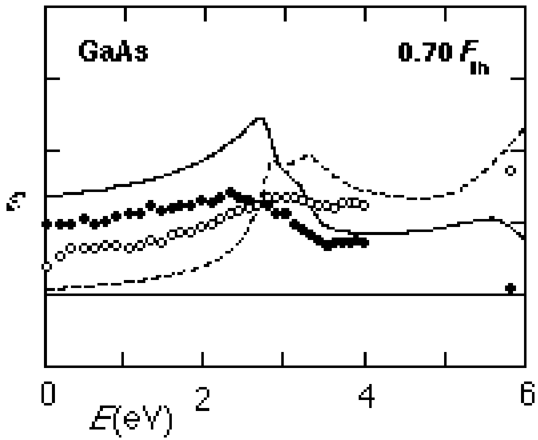
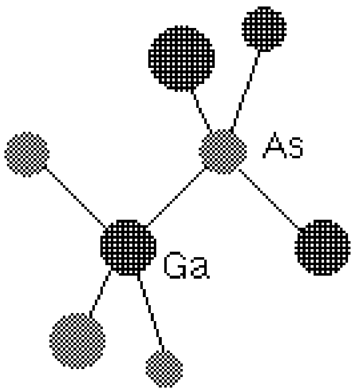
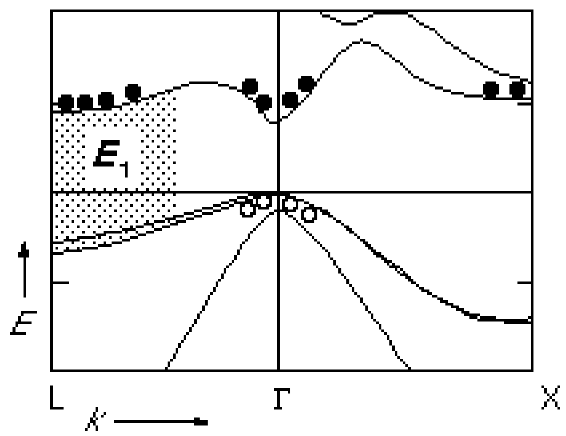


SHORT TIME SCALE (≈0.5 ps)

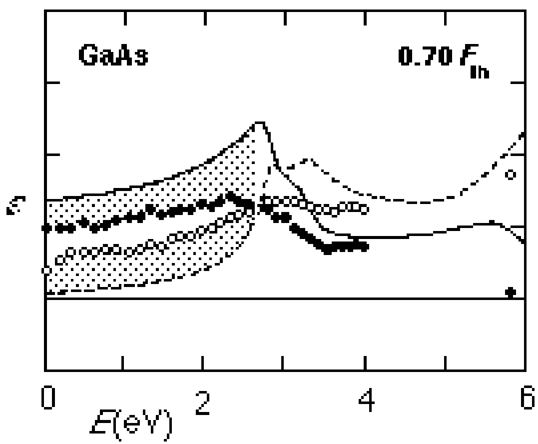
structure



bandstructure

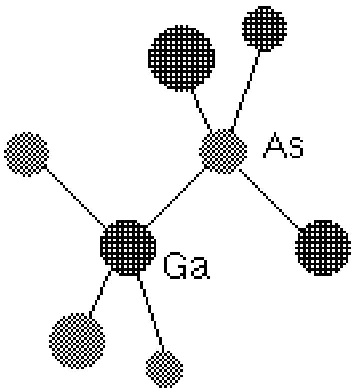


dielectric function

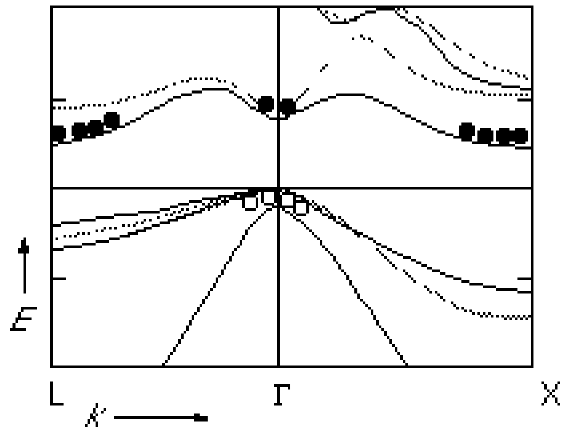


SHORT TIME SCALE (≈0.5 ps)

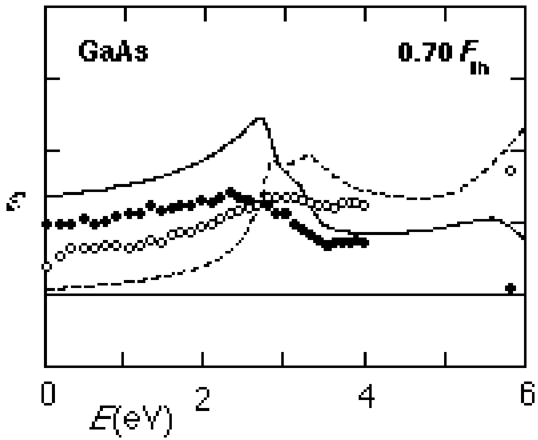
structure



bandstructure



dielectric function

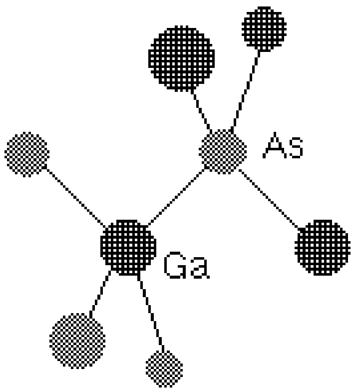


S. Froyen *et al.*, *Phys Rev. B* **28** (1983) 3258

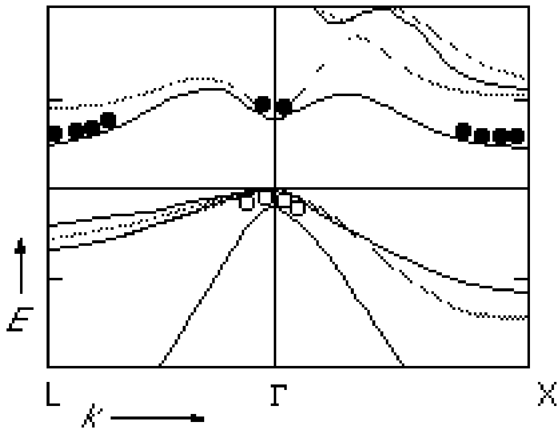
D.H. Kim *et al.*, *Sol. State. Comm.* **89** (1994) 119

SHORT TIME SCALE (≈0.5 ps)

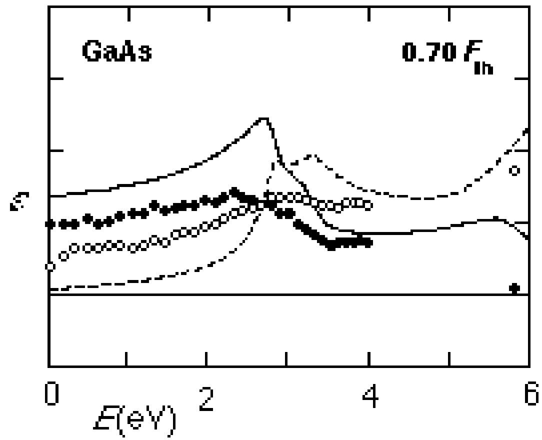
structure



bandstructure



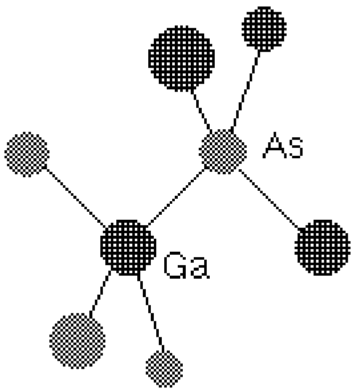
dielectric function



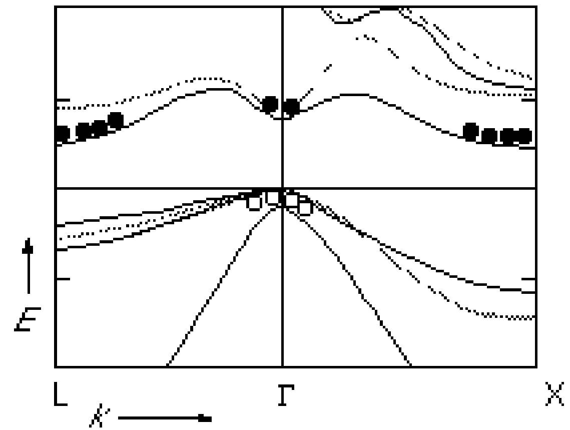
- electronic effects dominate at short time scales...

SHORT TIME SCALE (≈0.5 ps)

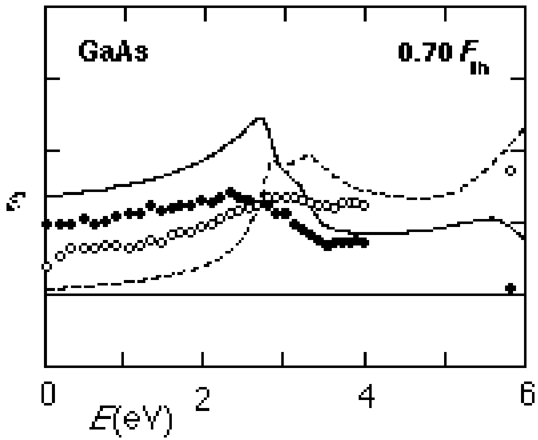
structure



bandstructure



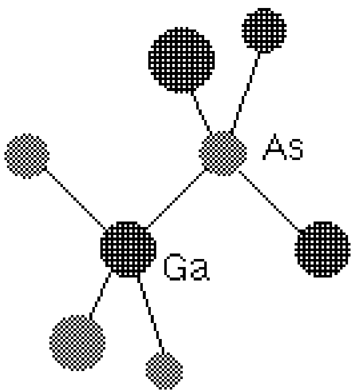
dielectric function



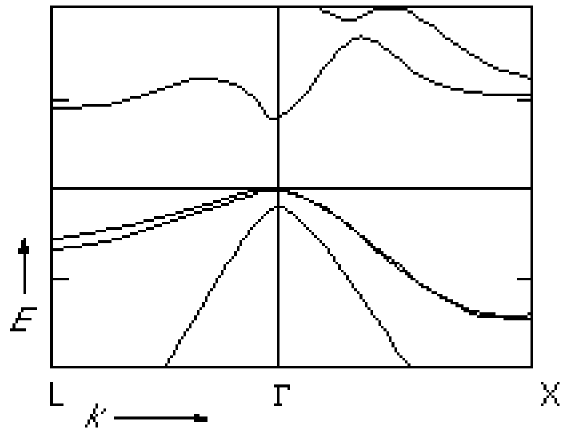
- ...but they are not as simple as we used to think

LOW FLUENCE, LONG TIME SCALE

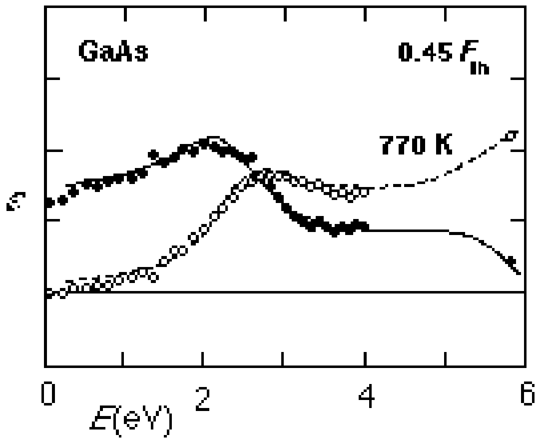
structure



bandstructure

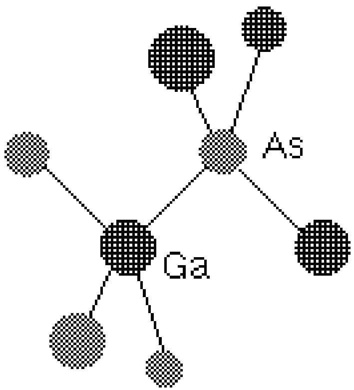


dielectric function

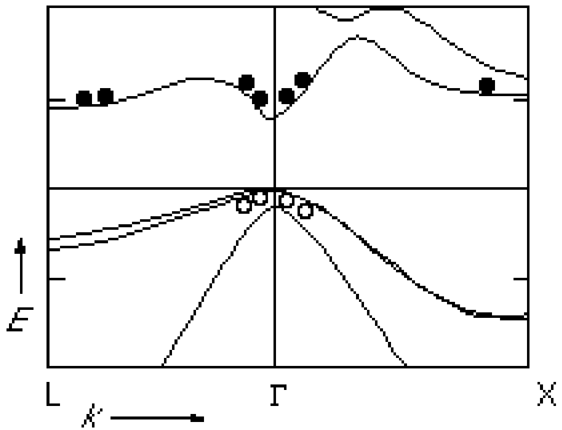


LOW FLUENCE, LONG TIME SCALE

structure



bandstructure



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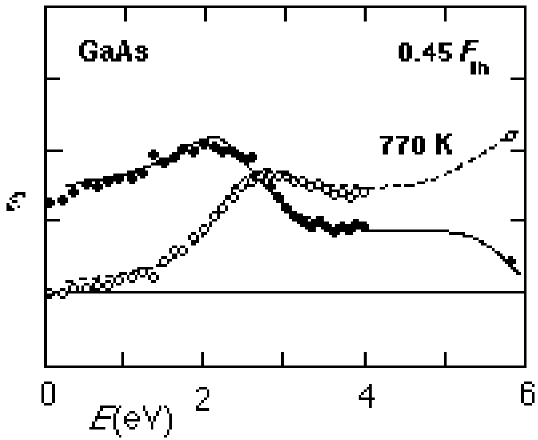
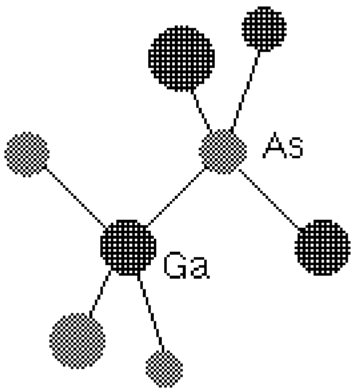


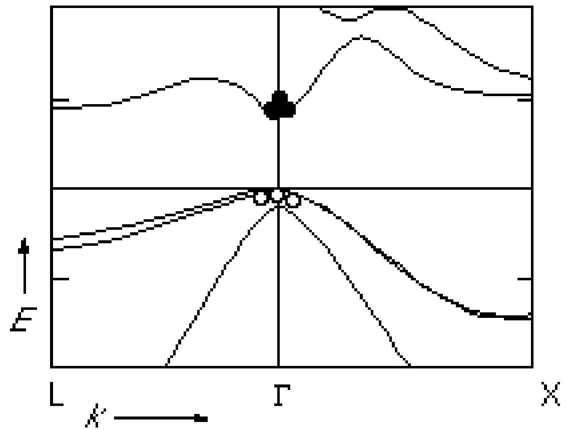
carrier density down, electronic effects subsided...

LOW FLUENCE, LONG TIME SCALE

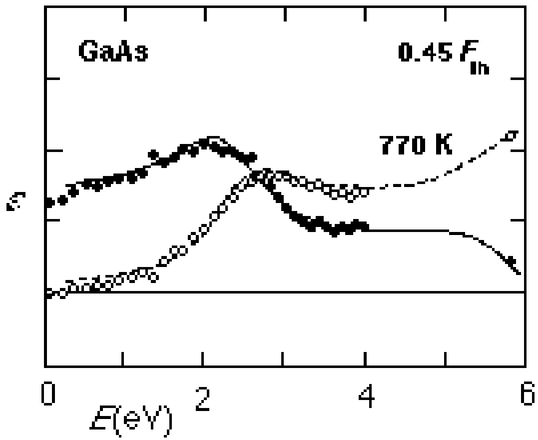
structure



bandstructure



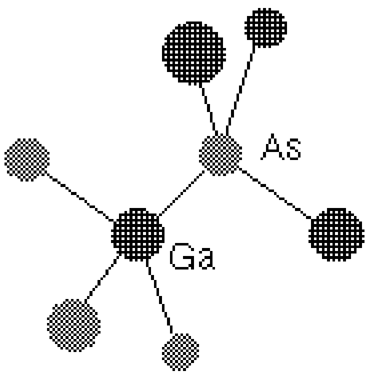
dielectric function



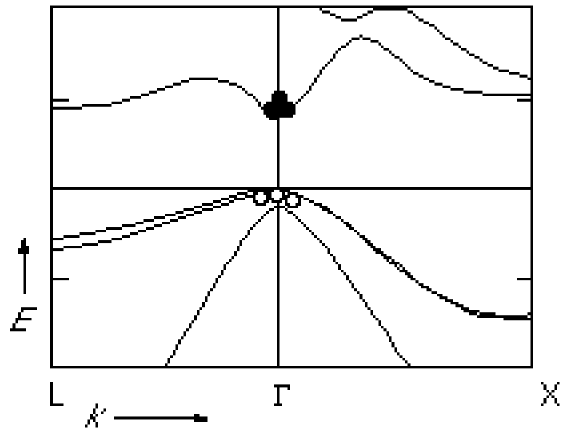
...and lattice heats due to carrier relaxation

LOW FLUENCE, LONG TIME SCALE

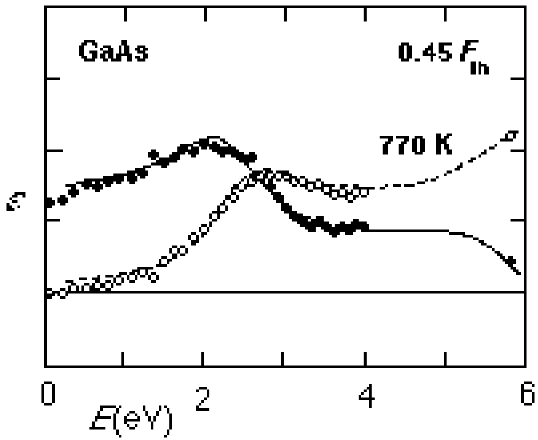
structure



bandstructure



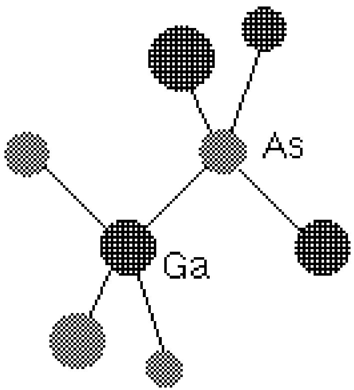
dielectric function



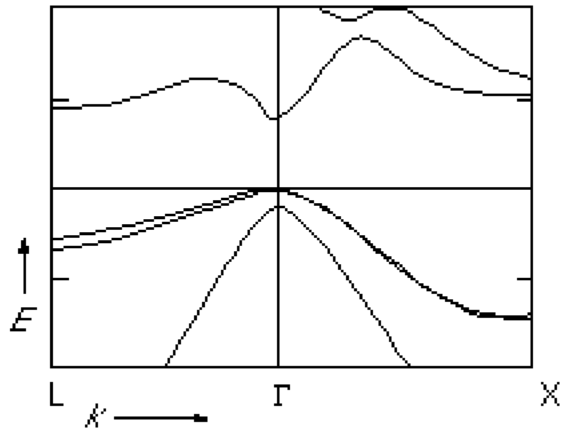
...and lattice heats due to carrier relaxation

HIGH FLUENCE, LONG TIME SCALE

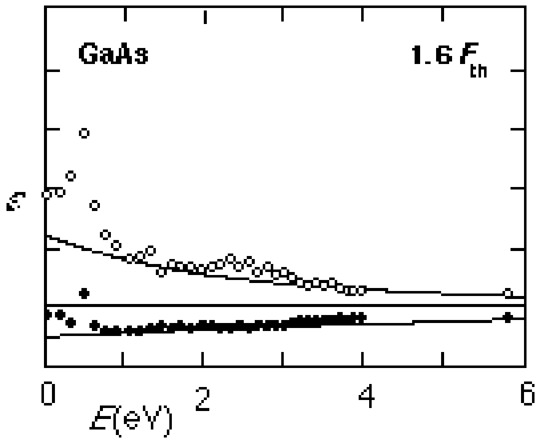
structure



bandstructure



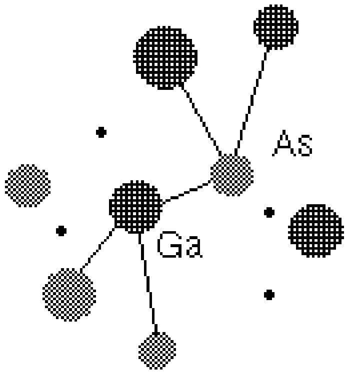
dielectric function



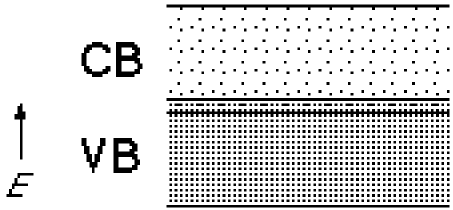
gradual drop in gap → not electronic effect

HIGH FLUENCE, LONG TIME SCALE

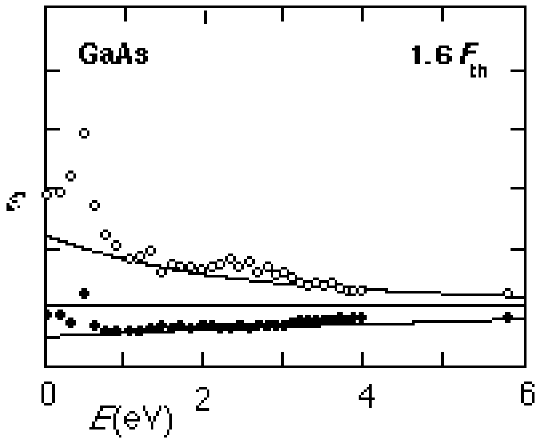
structure



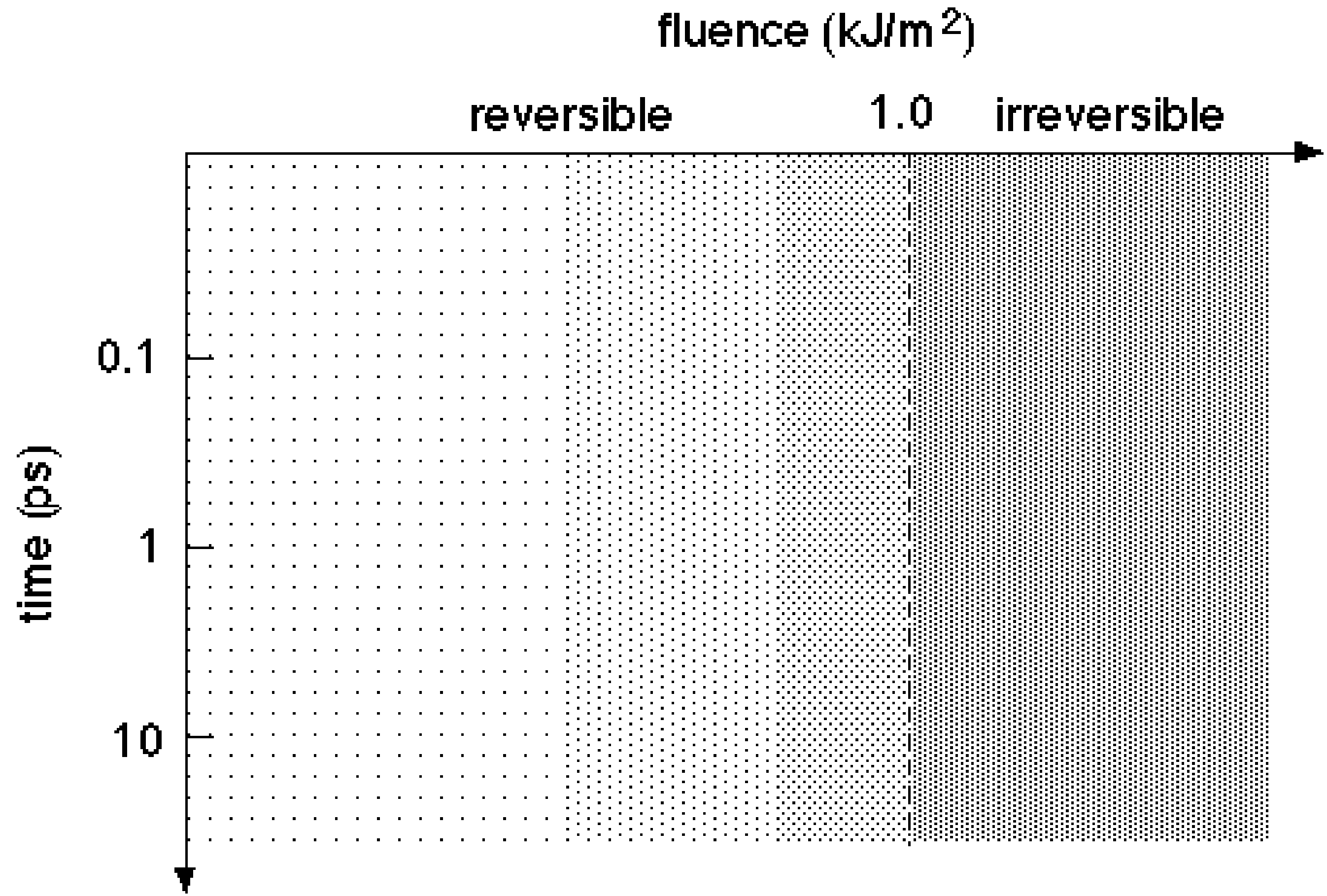
bandstructure



dielectric function



BROADBAND DATA



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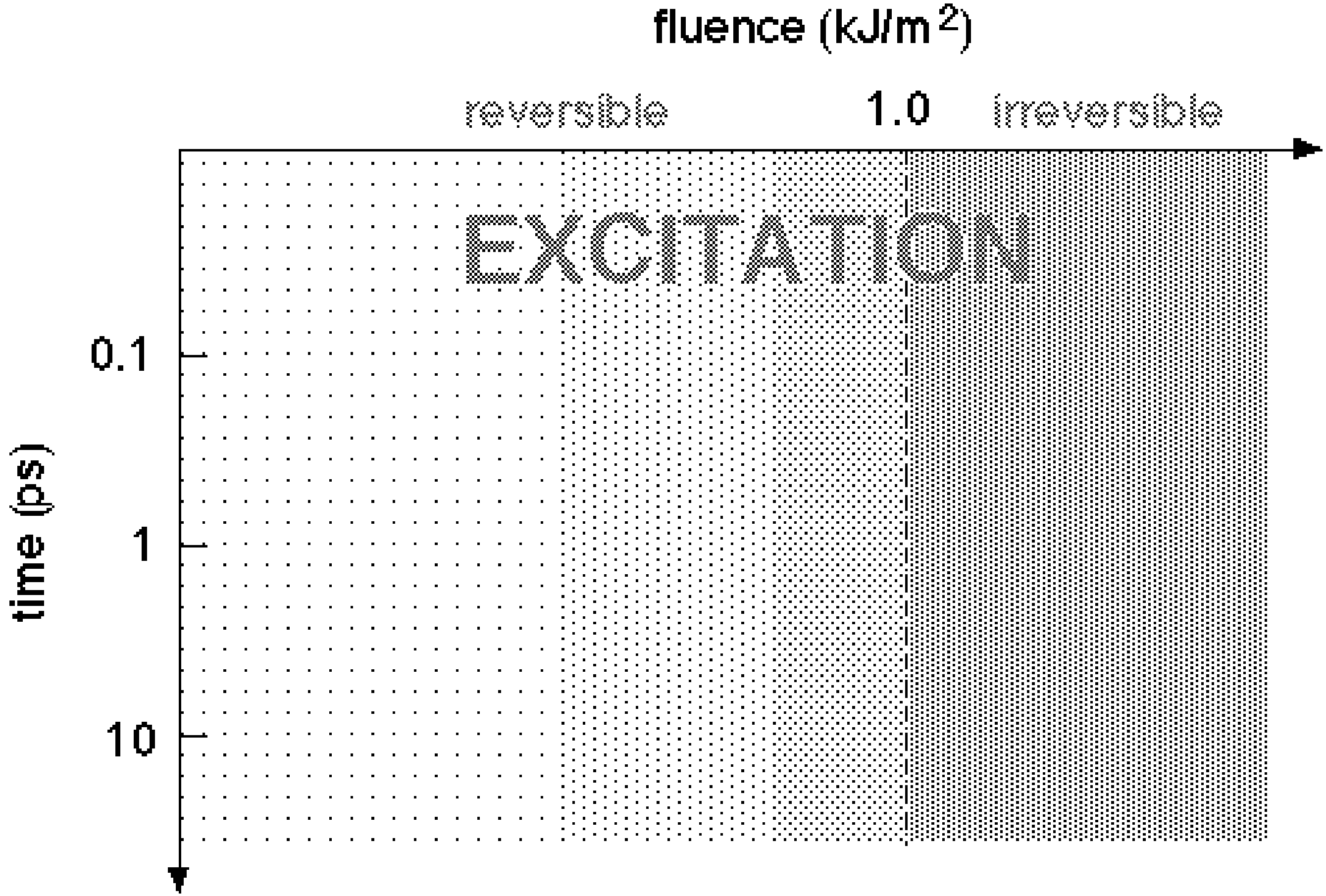

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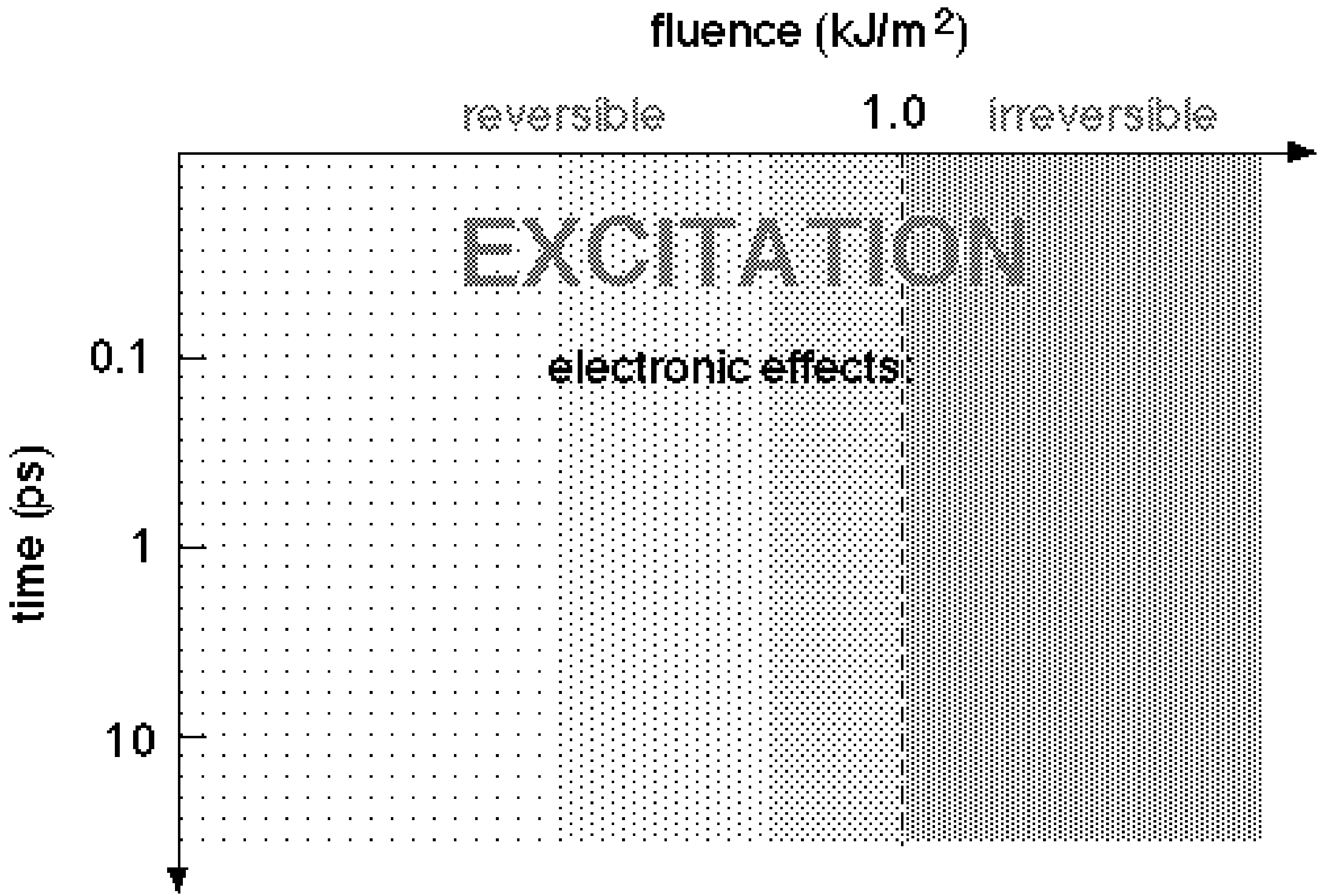

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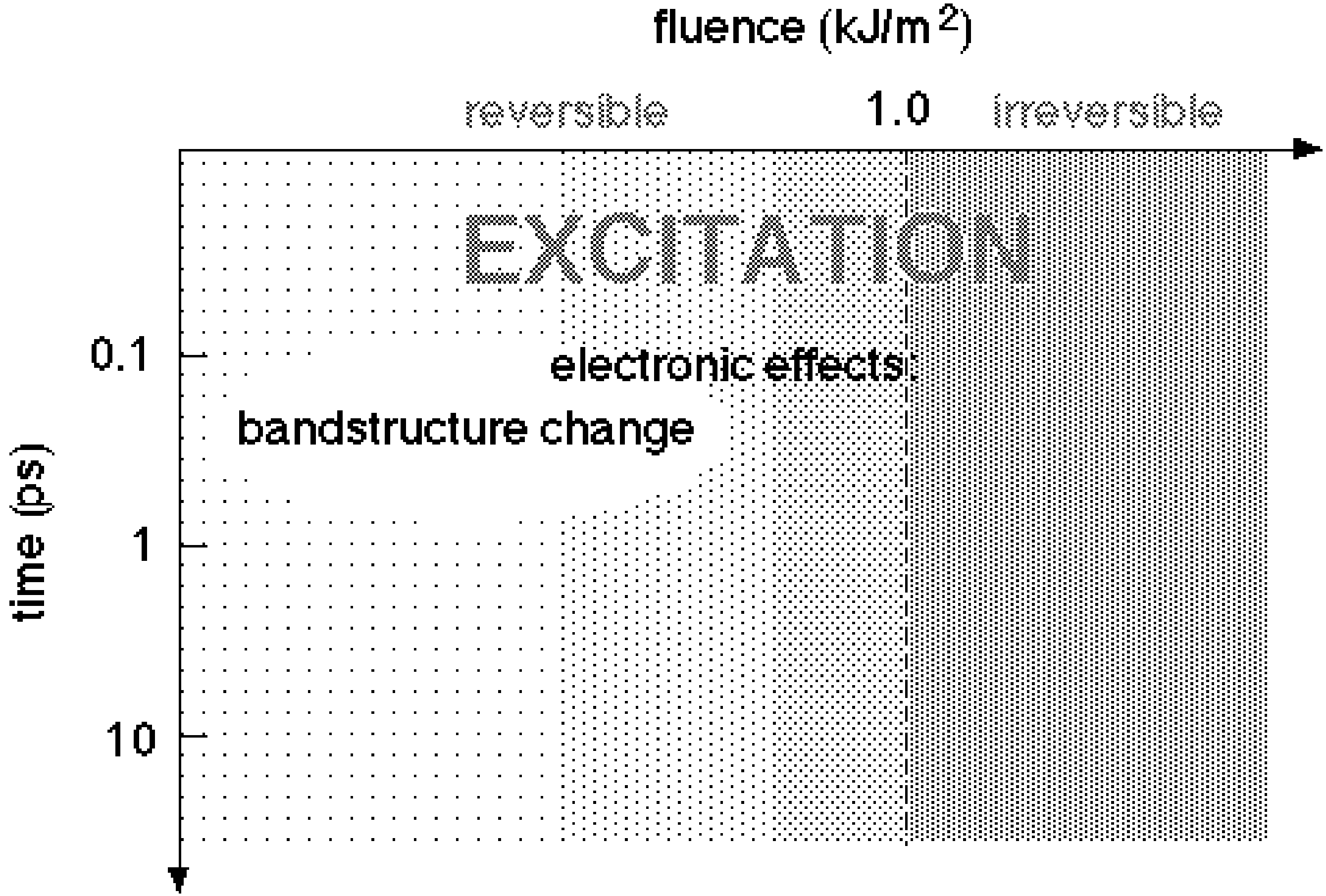

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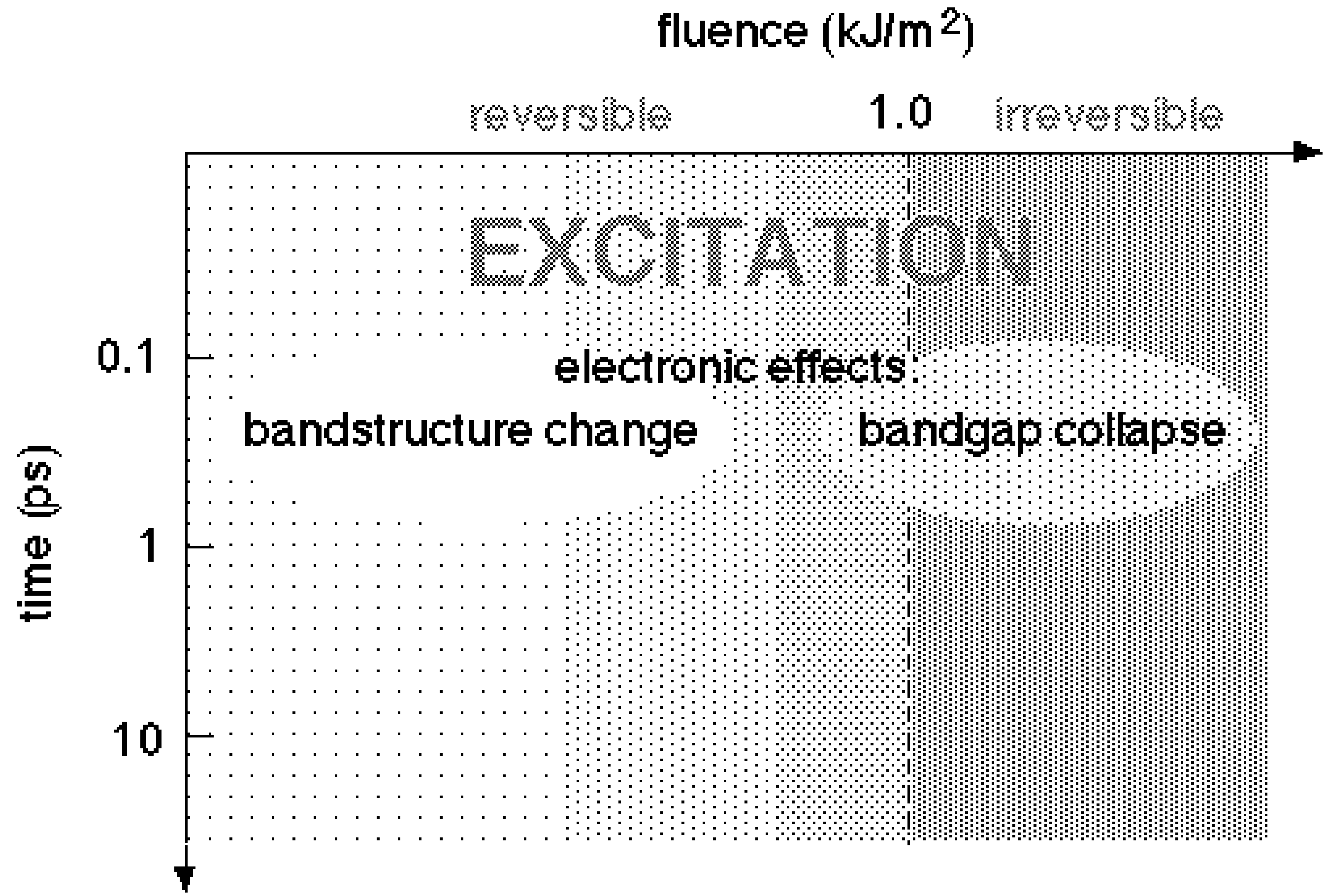

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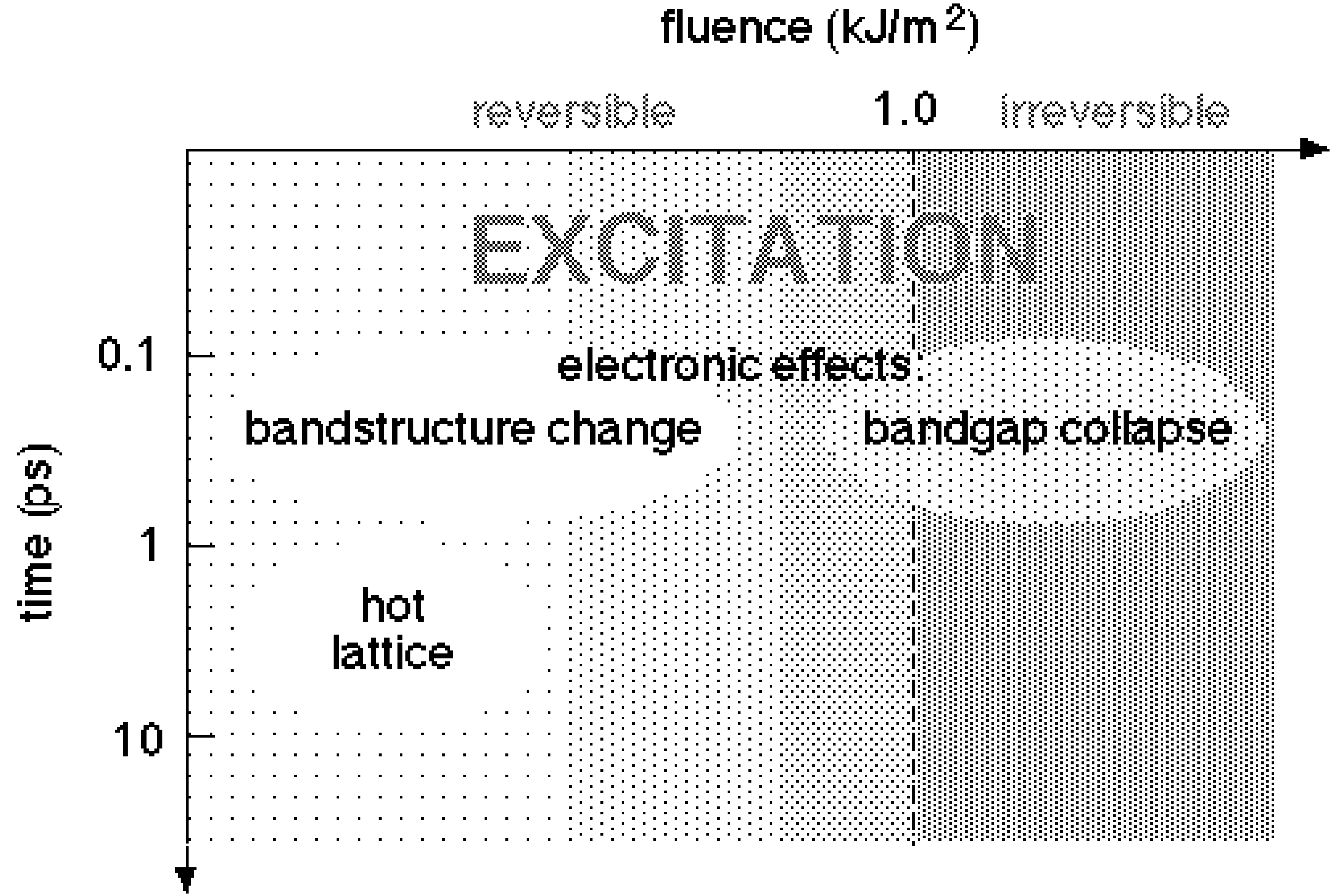

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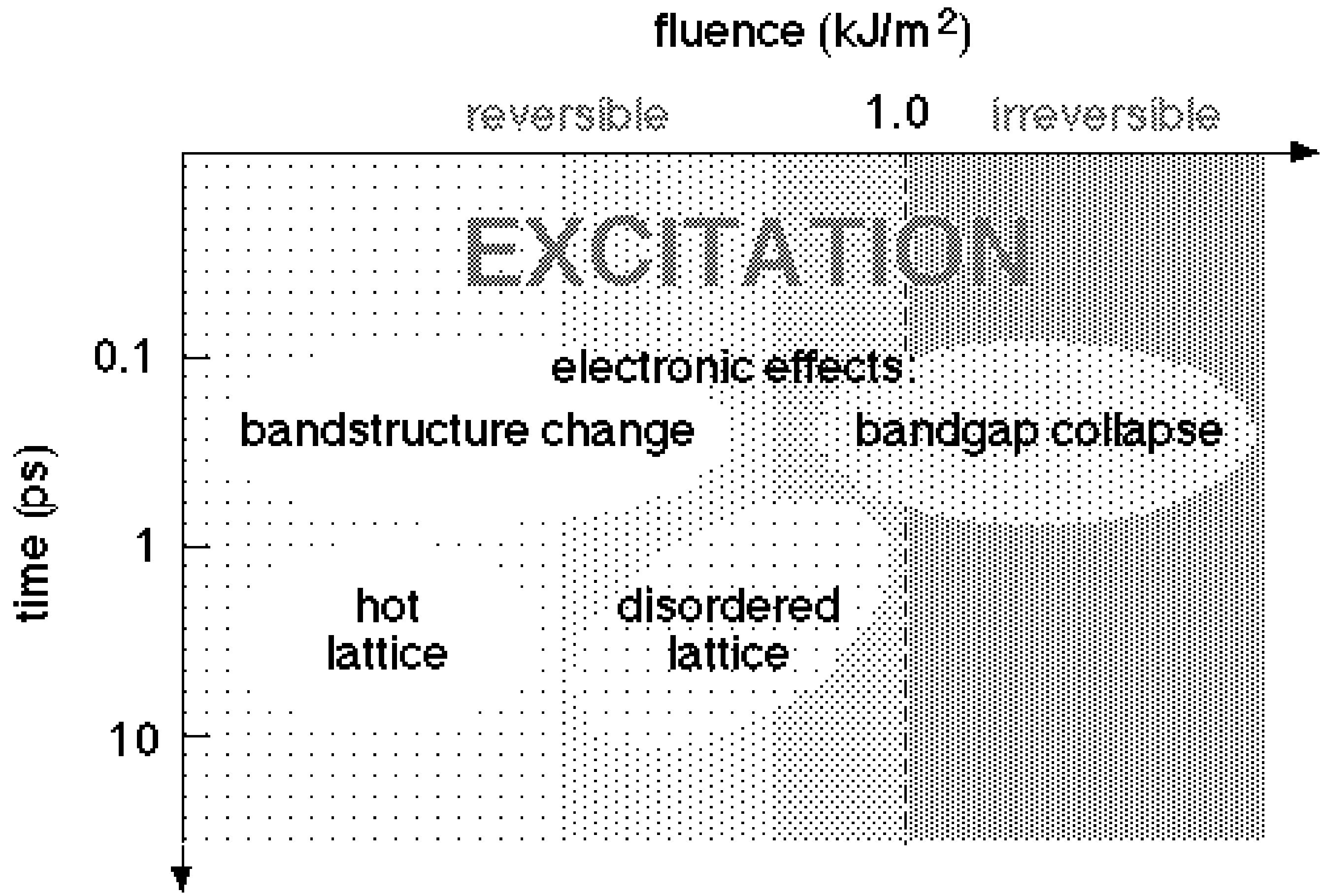

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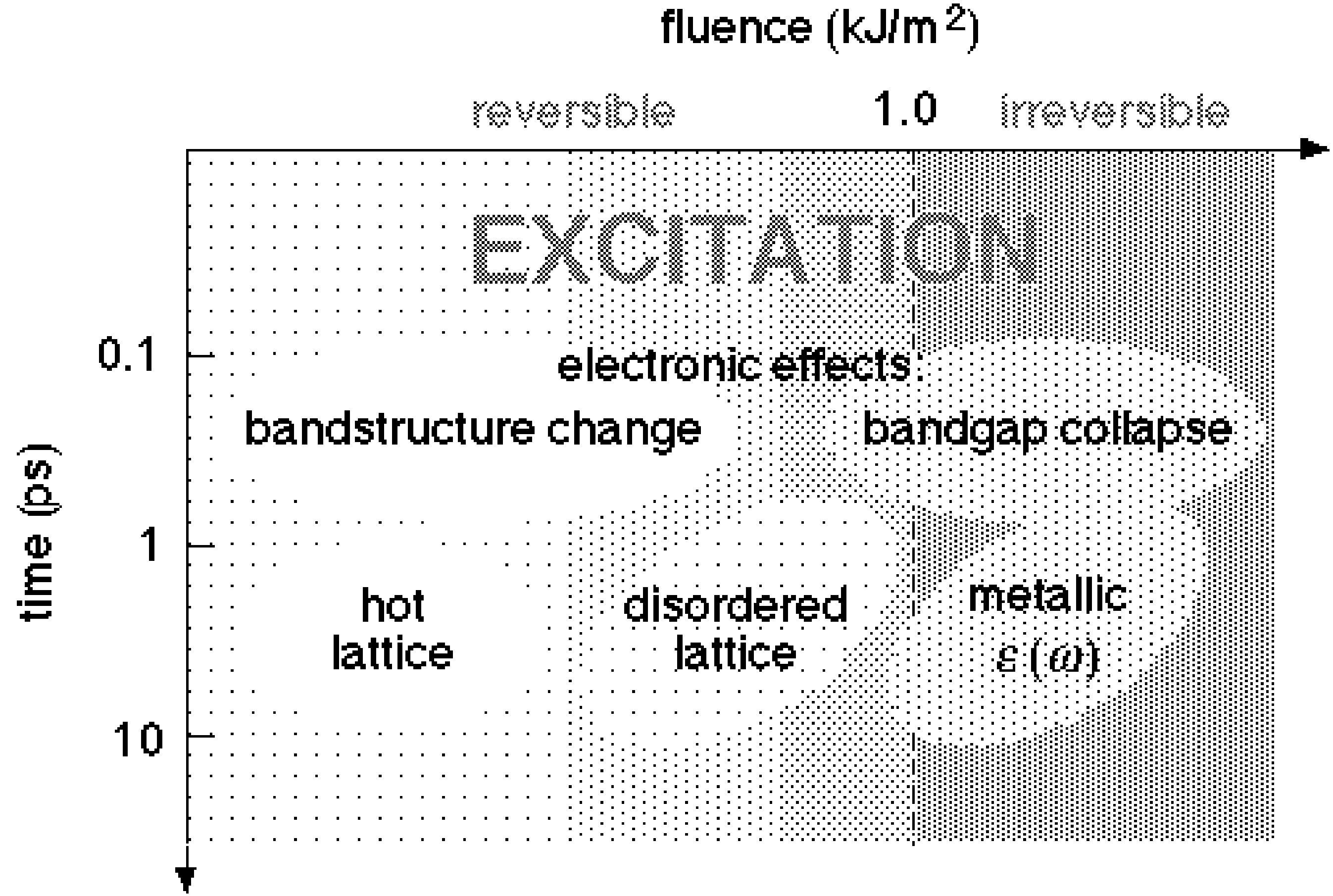

SUMMARY

- measurement of $\varepsilon(\omega)$ 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

CONCLUSIONS

- strong electronic excitation can drive a structural transition

- femtosecond lasers allow us to see the dynamics of the transition

Acknowledgments

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

ONR, NSF

http://mazur-www.harvard.edu