Ultrafast THz Pump-Probe experiment in BSTS

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Outline

- Topological Surface state
- Long lifetime of surface carrier in BSTS
- NIR pump-THz probe in BSTS experiment
- MIR pump-THz probe in BSTS experiment
  - -Pump-Probe system
  - -Experiment data
- Sumarry

Topological surface state

<u>Surface state of topological insulator (TI)</u>

- Linear Dirac dispersion
- Spin-momentum locking

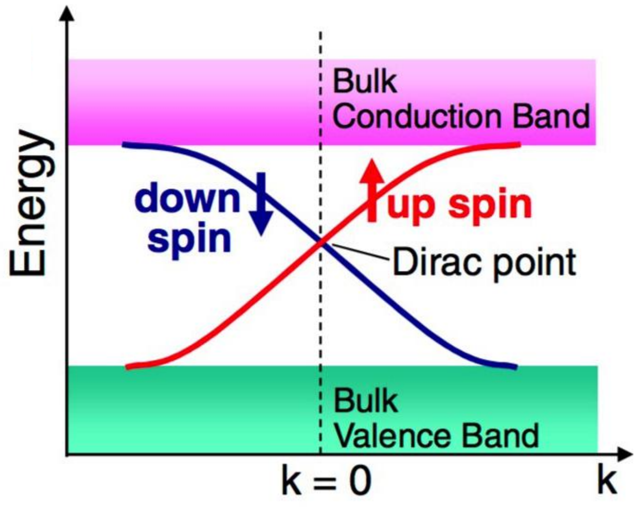
Application

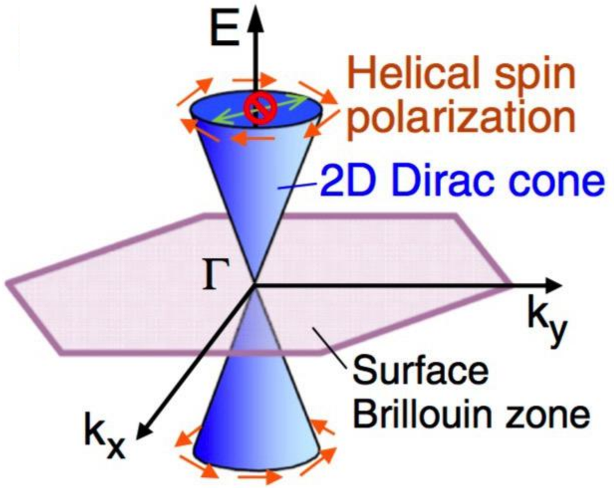
Electronics/spintronics devices

Magneto/Electro-optical device

Research interests

- (Ultrafast) Transport property
- Optical control of surface current

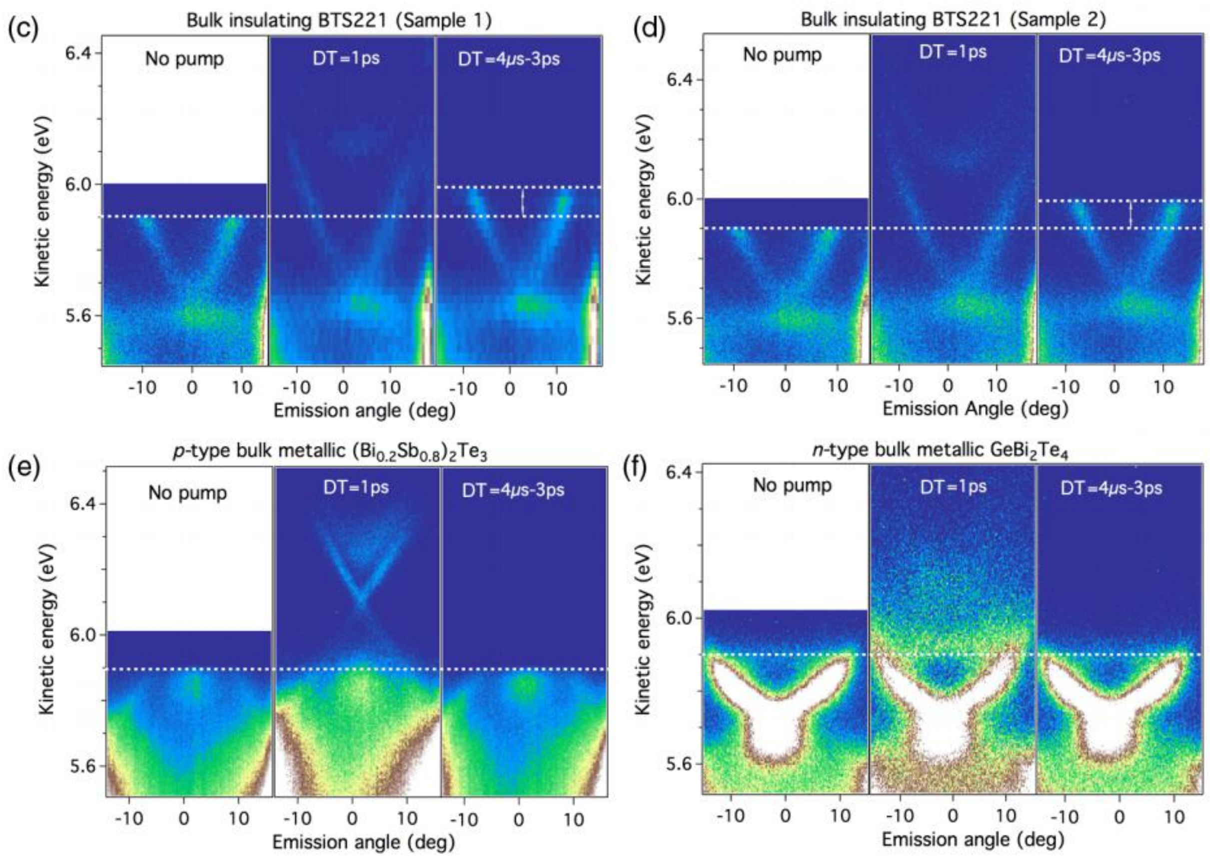


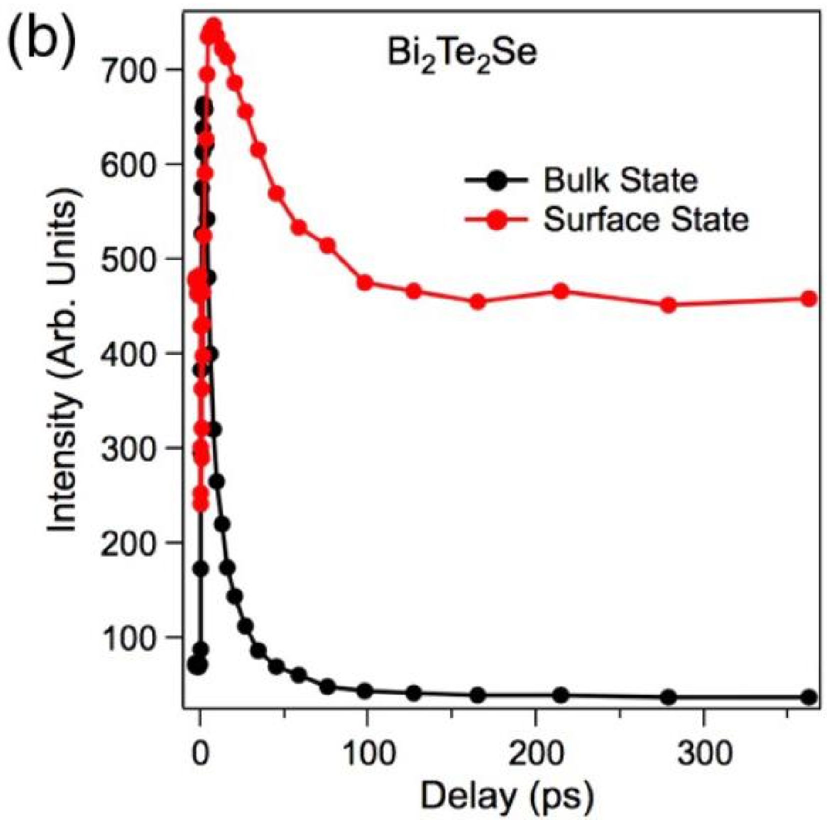


Y. Ando, J. Phys. Soc. Jpn. **82**, 102001 (2013).

Long lifetime of surface carrier

NIR pump- Tr-ARPES for Bi_2Te_2Se[1]

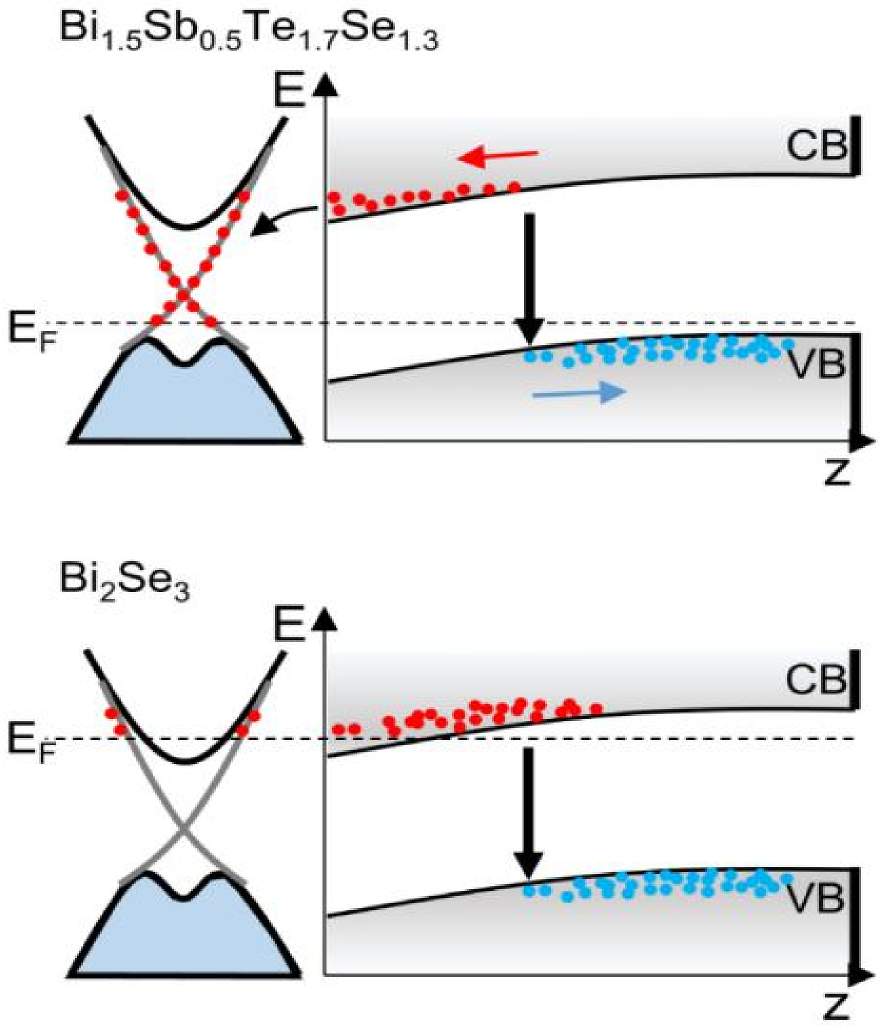




After NIR (800 nm) excitation
Bulk carrier diffusion < 100 ps
Slow surface carrier relaxation >> μs

[1] Neupane et al., PRL 115, 116801 (2015)

Long lifetime of surface carrier

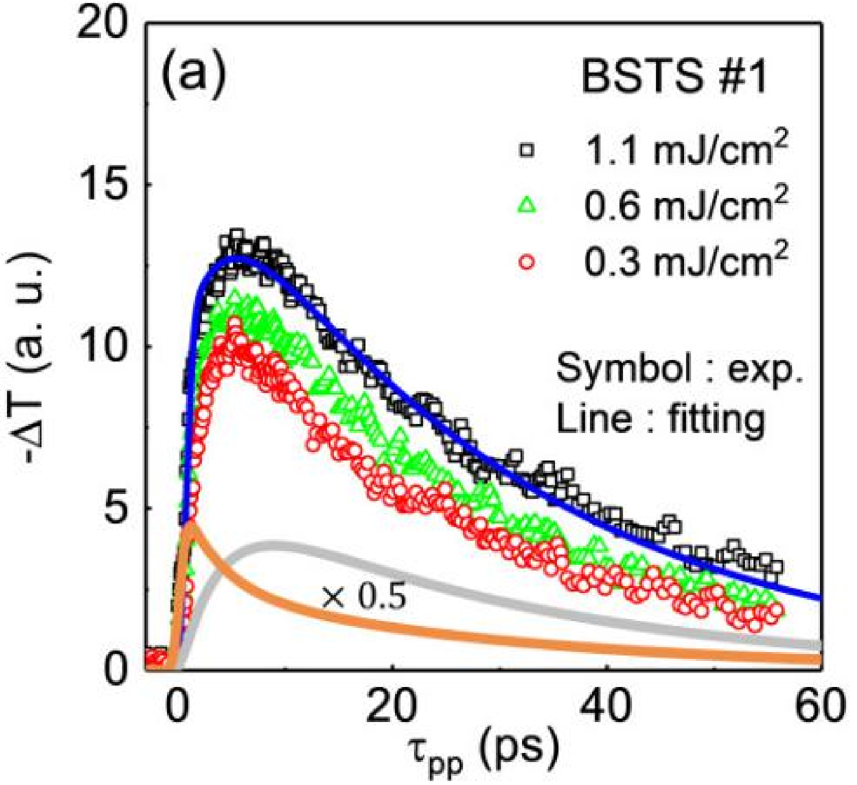


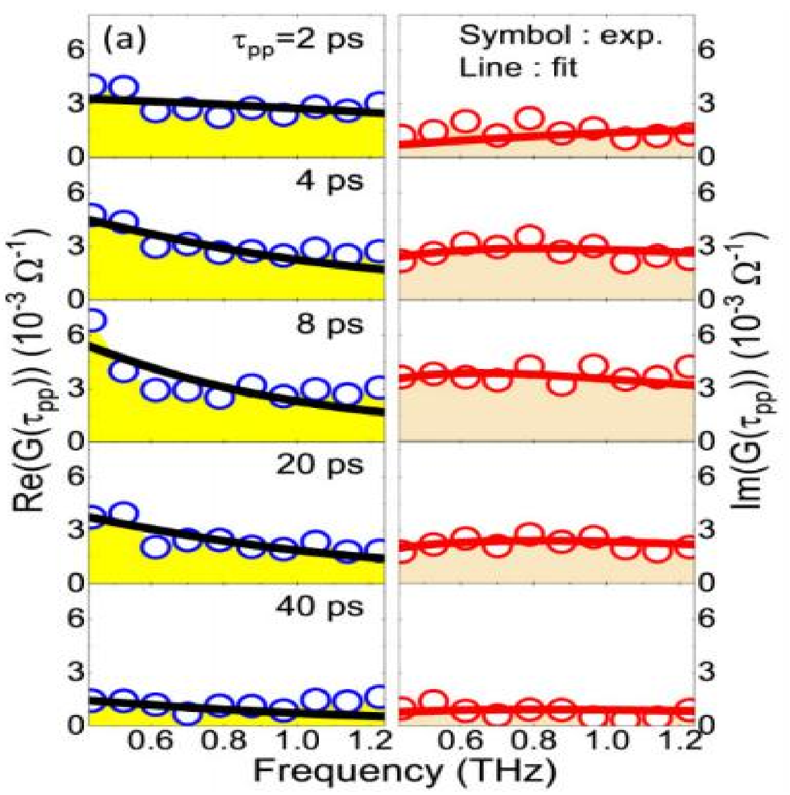
For BSTS, photoexcited and holes are accelerated in the opposite directions.
The confined electrons in the surface state are recombined with bulk holes through the surface-to-bulk transition.

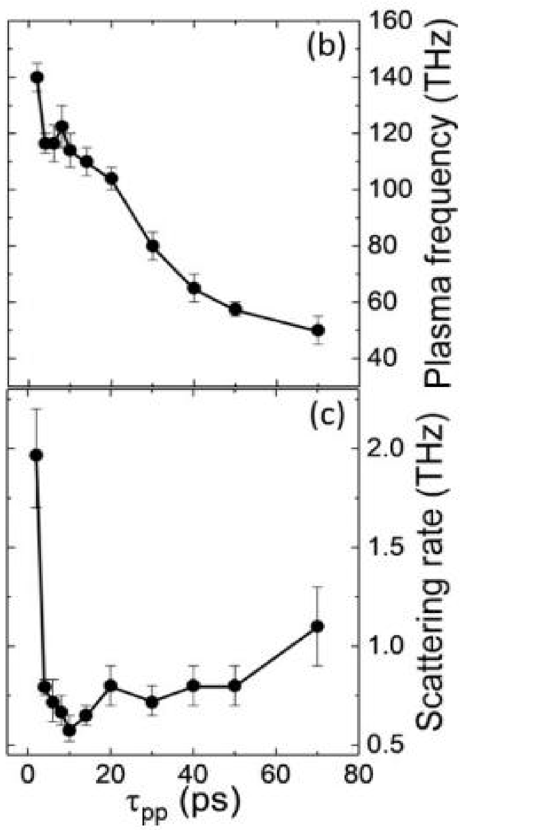
For Bi2Se3, the Fermi level is located crossing the conduction band, The transfer events from the bulk to surface occurs much less than for BSTS.

Choi, Young Gwan, et al. *Physical Review B* 97.7 (2018): 075307.

NIR pump-THz probe in BSTS



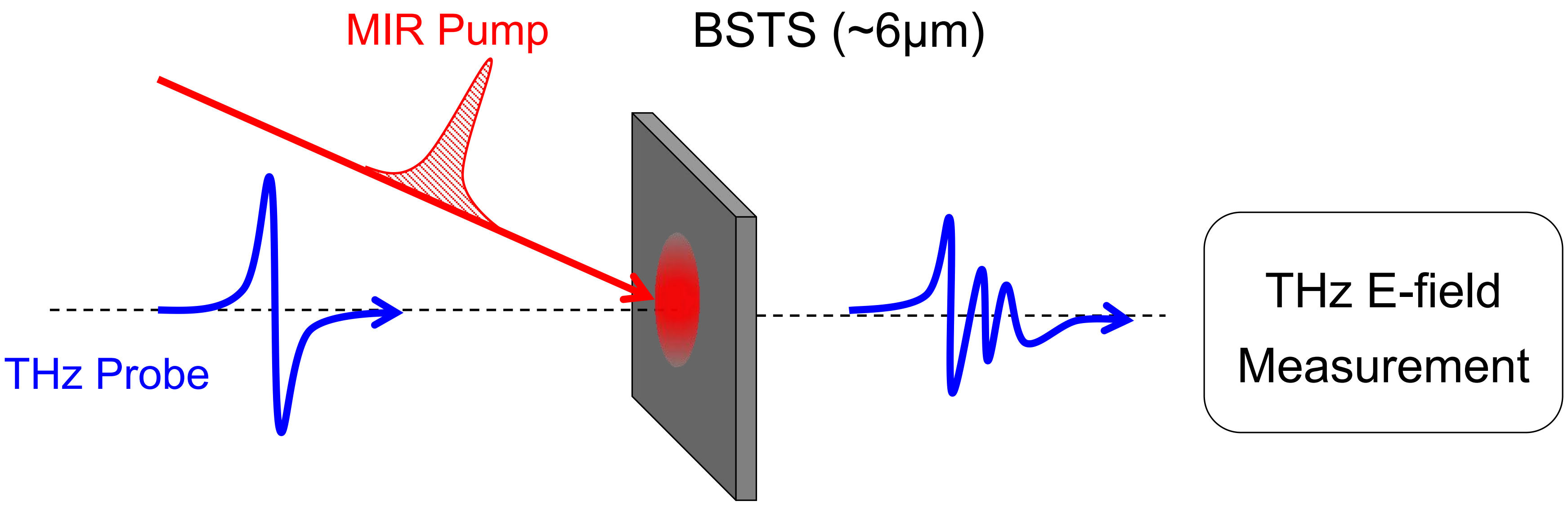




After NIR (800 nm) excitation
Bulk carrier diffusion < 60 ps
Slow surface carrier relaxation >> μs

Choi, Young Gwan, et al. *Physical Review B* 97.7 (2018): 075307.

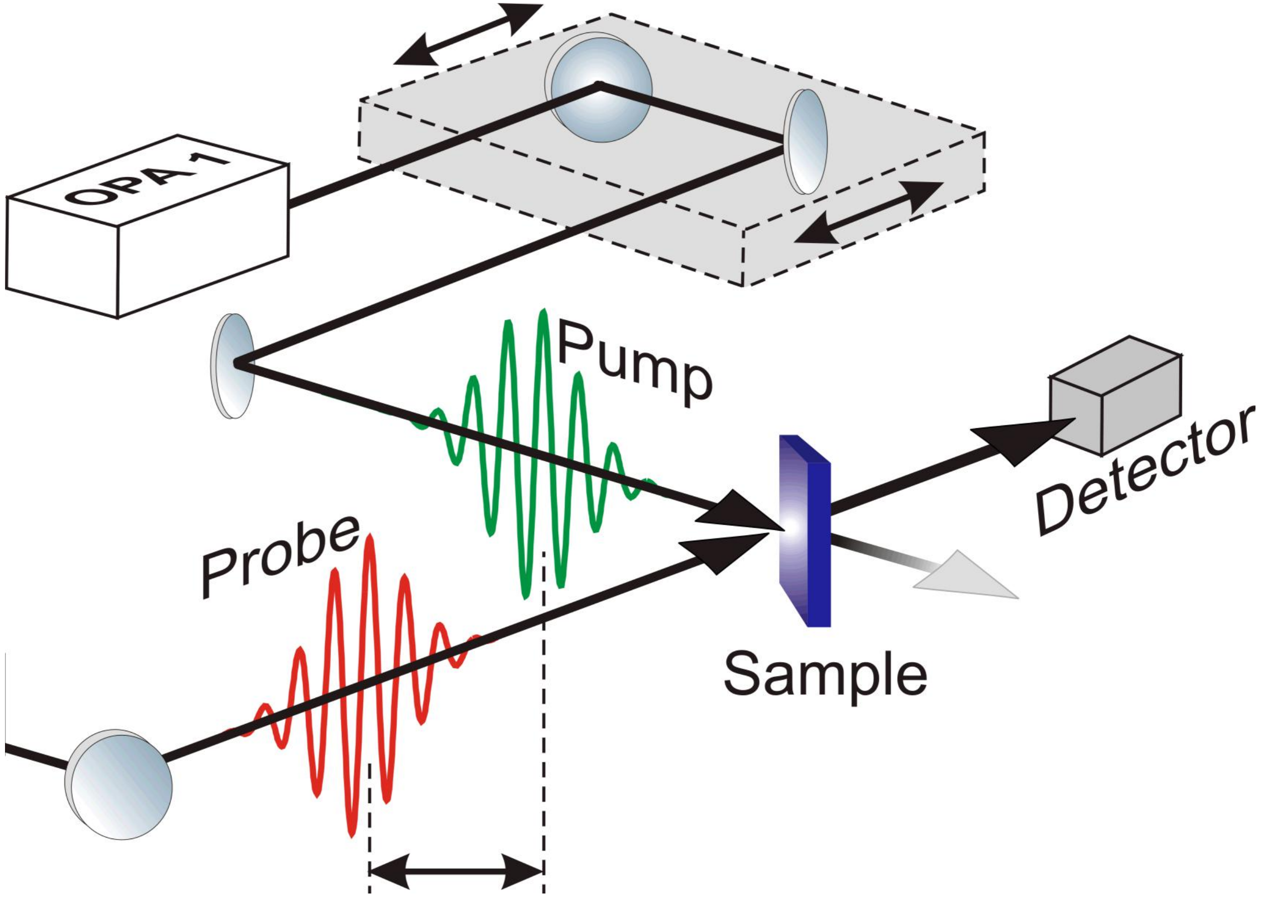
MIR pump-THz probe experiment



Pump: λ= 8 μm, (~ 0.155 eV) Pulse width ~ 100fs
P_{MIR} ~ *8~0.9* mW Repetition ~ 1KHz
below band gap excitation

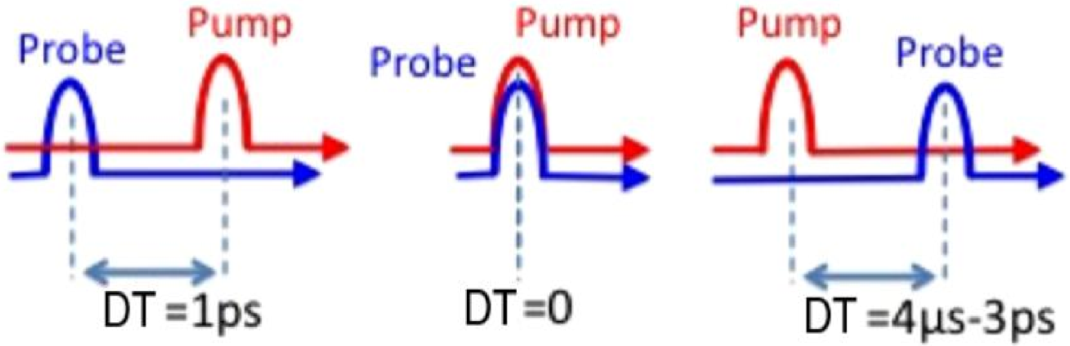
Probe: (THz) 0.4 – 7 THz (13-233 cm^{-1})
Probe the Drude response of photoexcited carrier

Pump-Probe system



Schematic view of the pump-probe system

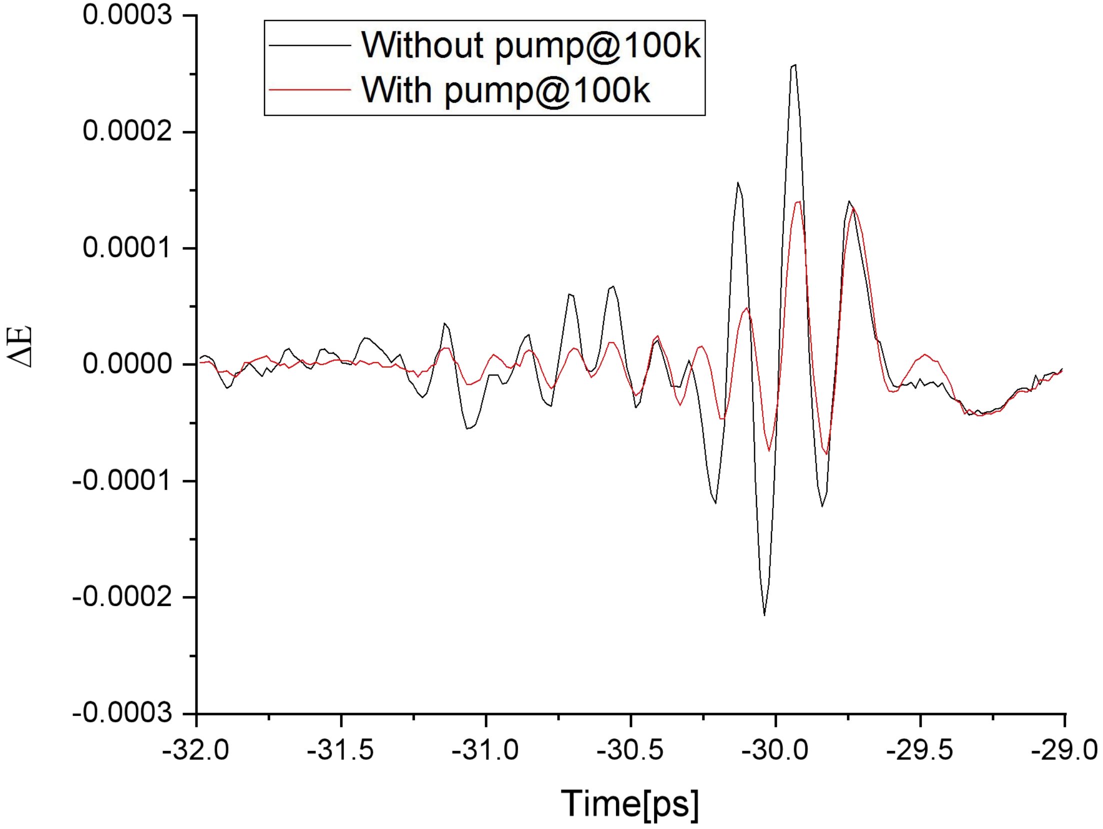
[3] Neupane et al., PRL 115, 116801 (2015)



Delay time between pump and probe beam

By changing the delay time , the optical properties before/after excitation can be measured!

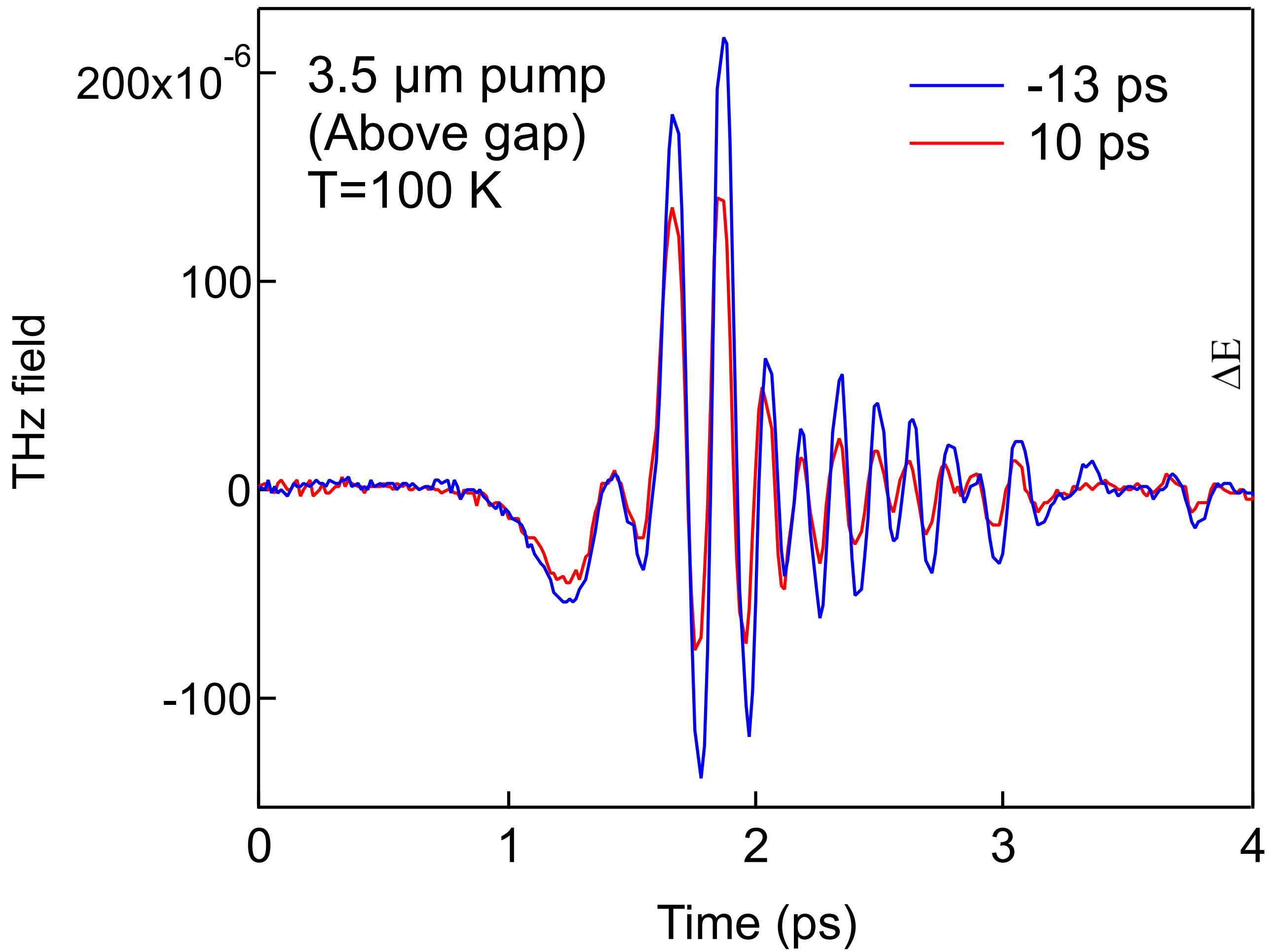
THz spectroscopy with/without pump



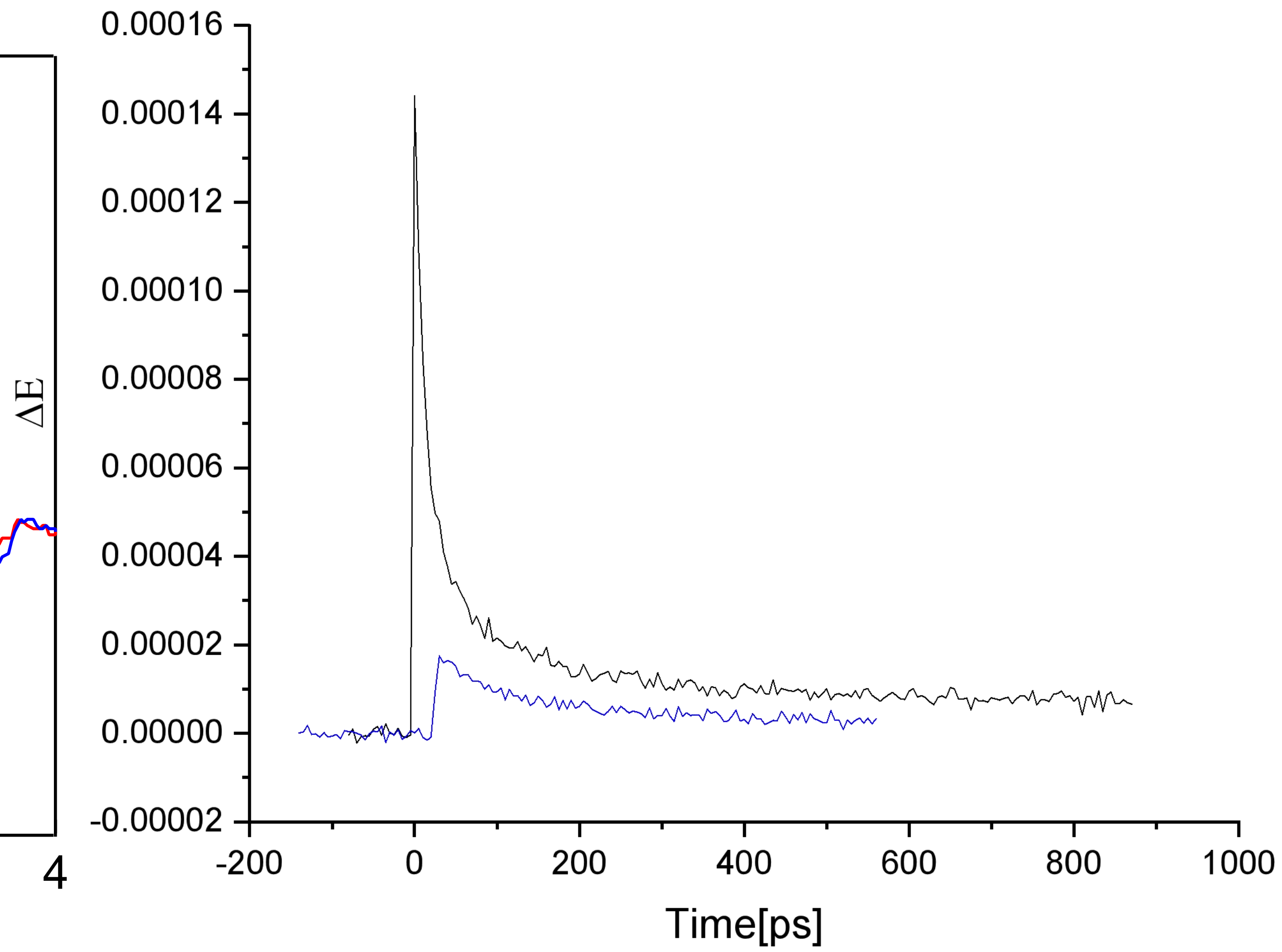
THz spectroscopy with/without pump

- There is an obviously energy change when the pump is open.
- The thermal carrier is activated when the pump is open.

THz peak field change



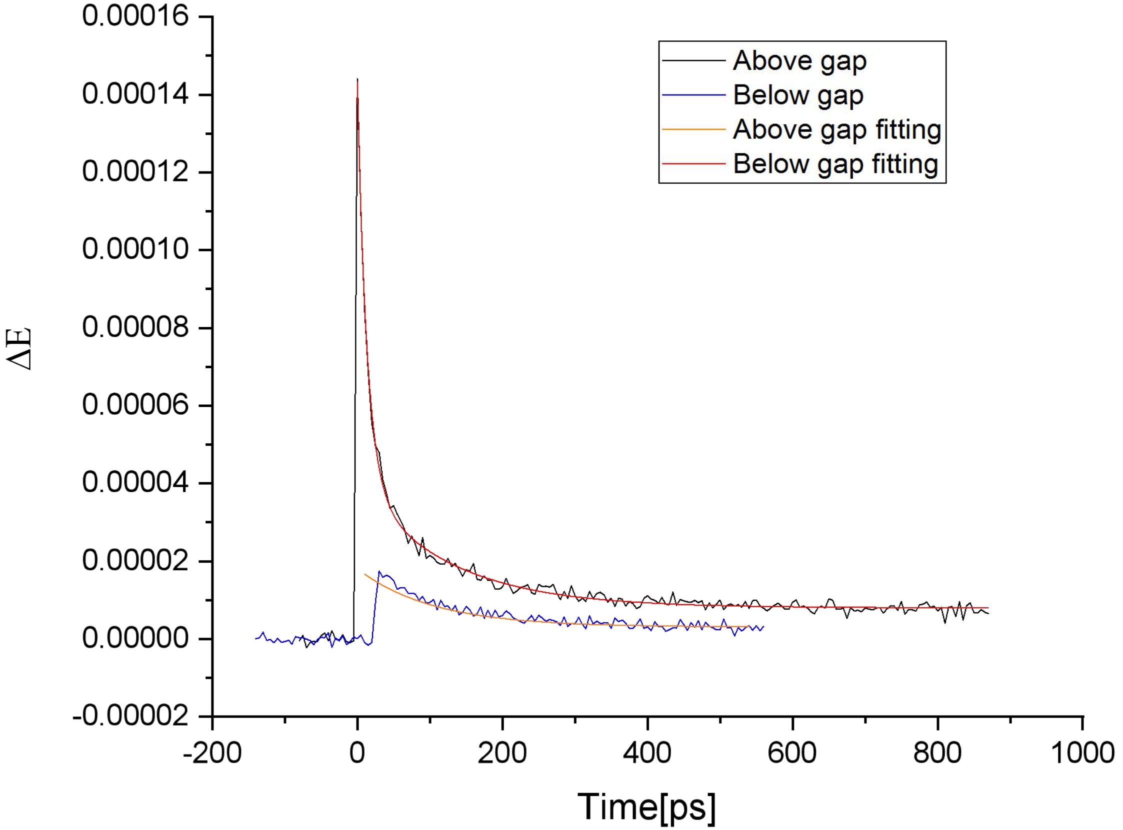
The THz wave in different position



The above/below band gap decay profiles of transient THz peak field at 100k

Modeling the change of Amptitude of THz field

Expectation



The above/below band gap decay profiles of transient THz peak field at 100k

The above band gap dispersion can be simply described by the combination of two exponential function.

$$Y_1 = 8\times 10^{-6} + 1\times 10^{-4}e^{-x/13.3} + 3\times 10^{-4}e^{-x/124}$$

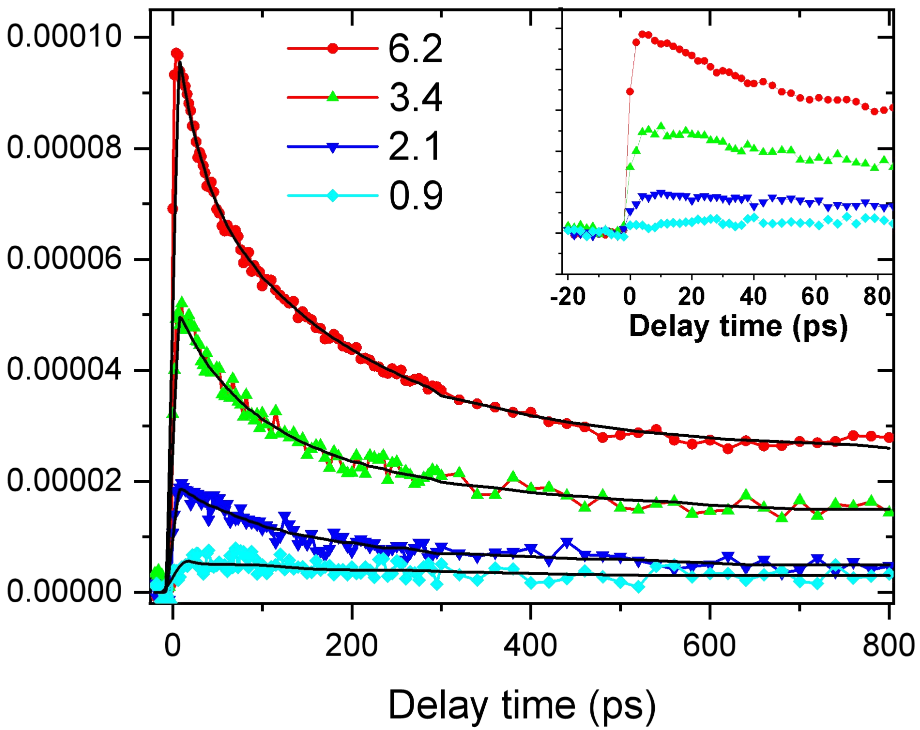
Bulk state and surface state

The below band gap dispersion shows only one exponential dispersion.

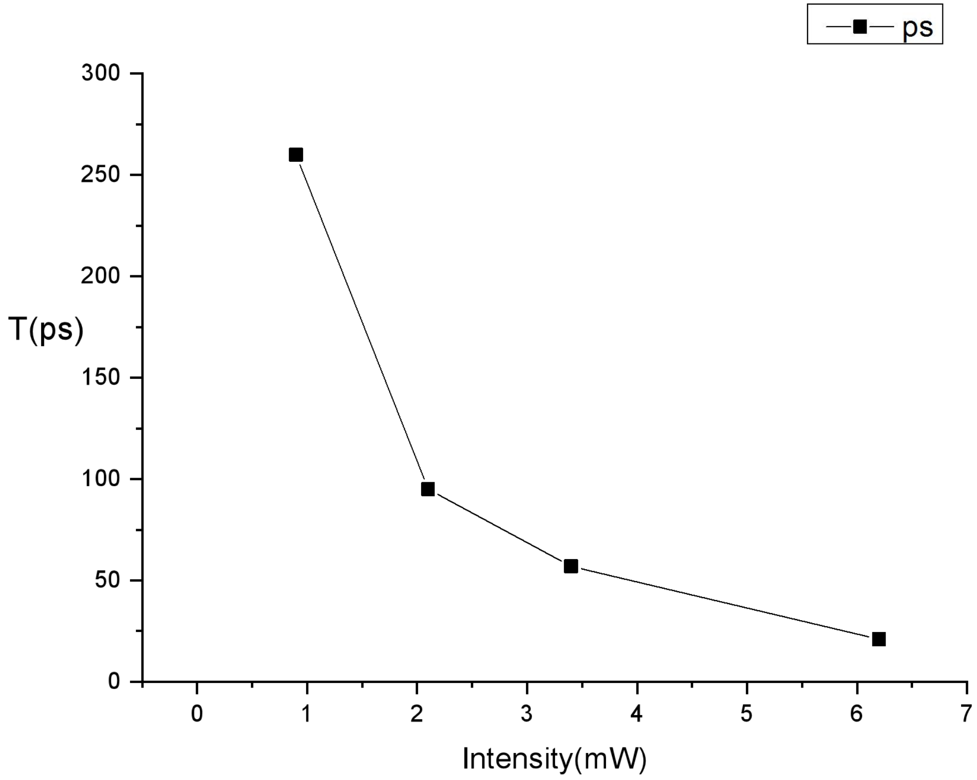
?

Surface state

THz field change



MIR pump (8μm)- THz probe THz field change ΔE_{THz}



Effective lifetime with different pump intensity

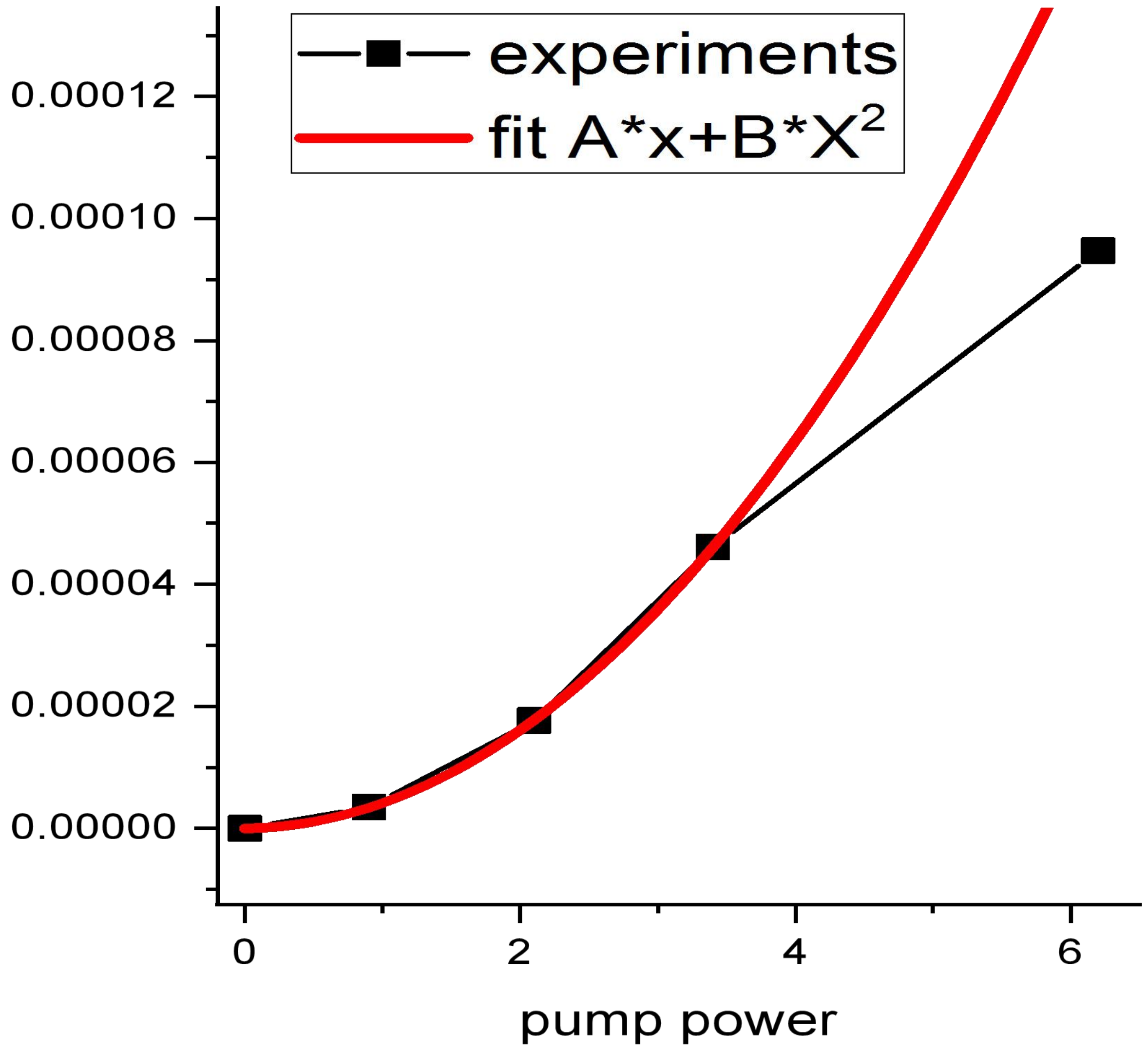
The THz field change can well fit with two exponential function.

Two decay processes.

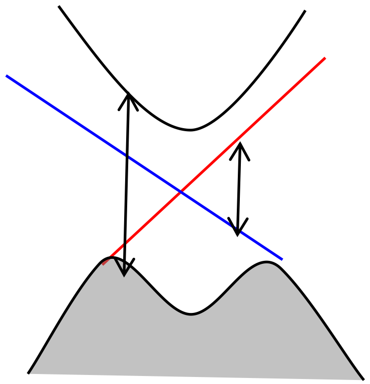
With increasing intensity, the effective life time becomes shorter.

Number of photon effects the the life time.

Below gap pump



THz peak high change by pump power



Below gap pump:

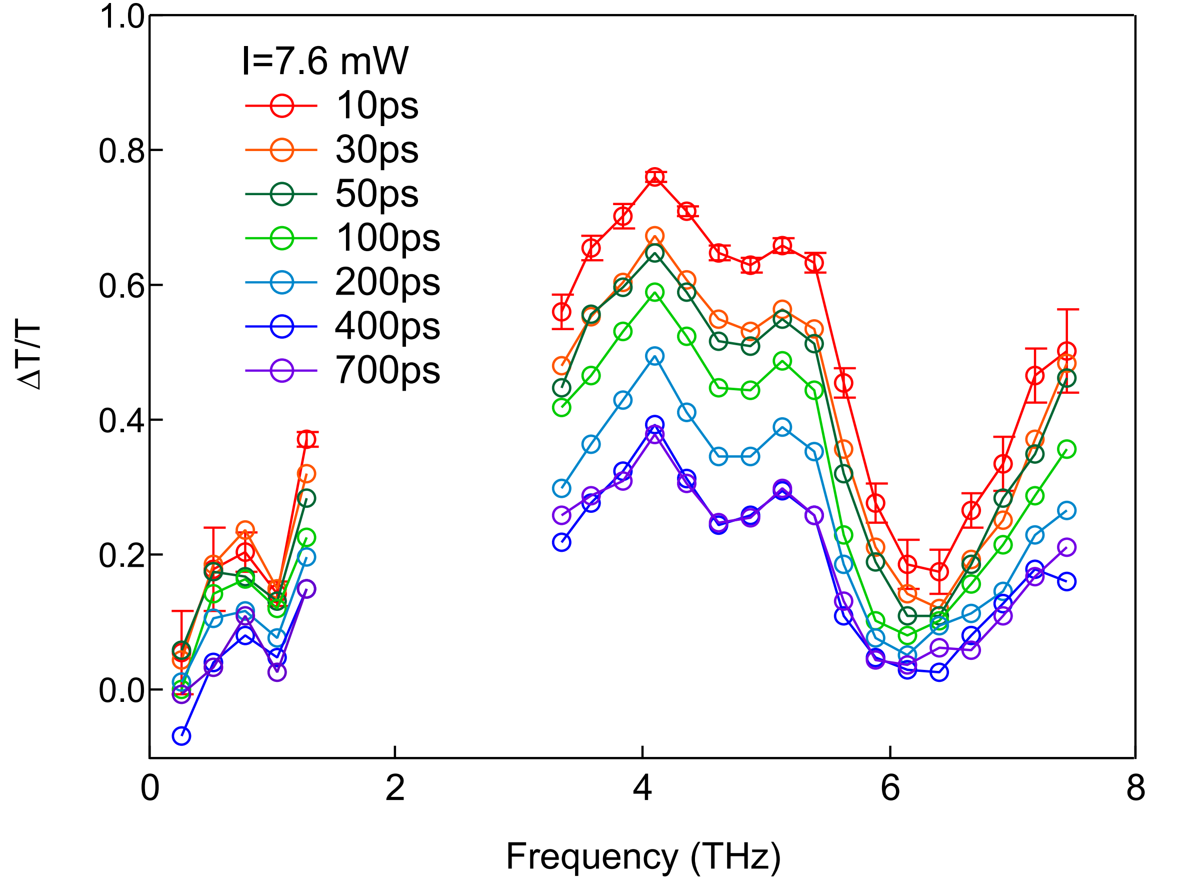
- Bulk to bulk(two photons absorption)

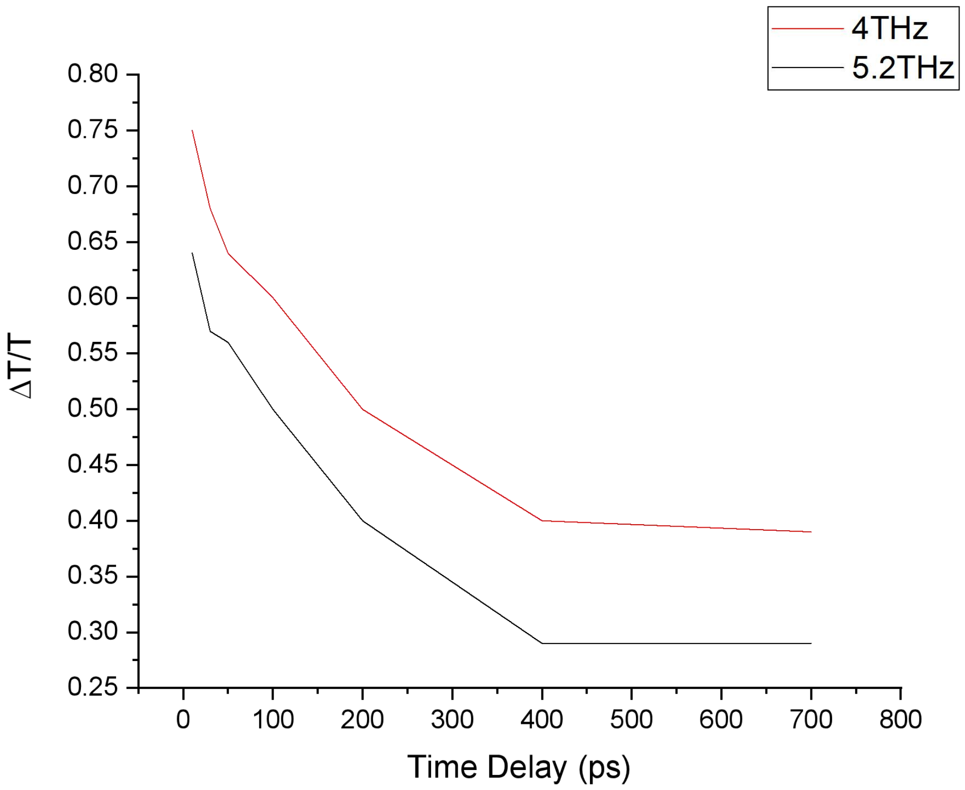
  Band gap energies≈0.3ev

  pumpbeam energies≈0.15ev

- Surface to surface(one photon absorption)

Transmittace change at different delay time

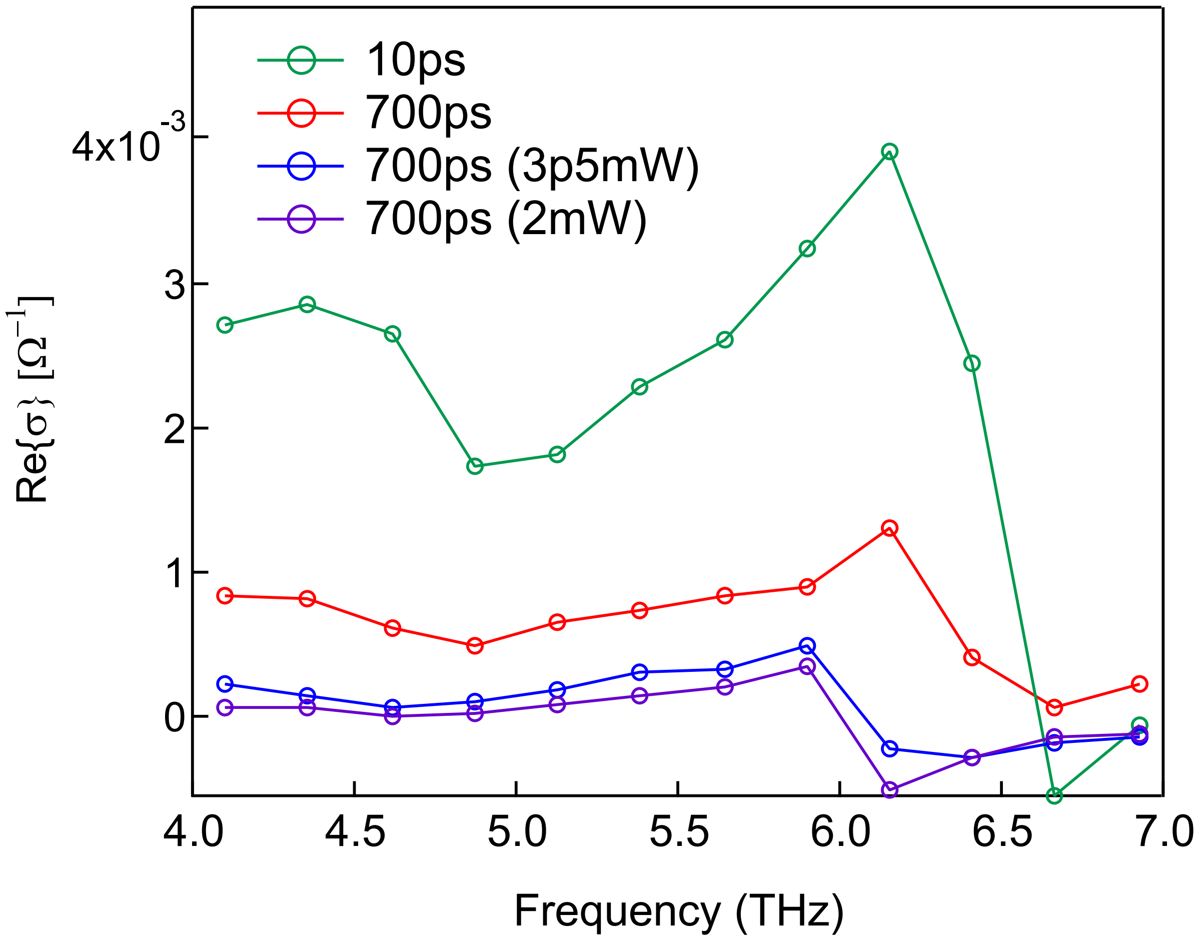




$$(\Delta T / T) = (T_{\tau>0} - T_{\tau<0}) / T_{\tau<0}$$

Transmittace becomes smaller in longer decay time, but we can still see an offset after 700ps.

Photo induced optical conductance



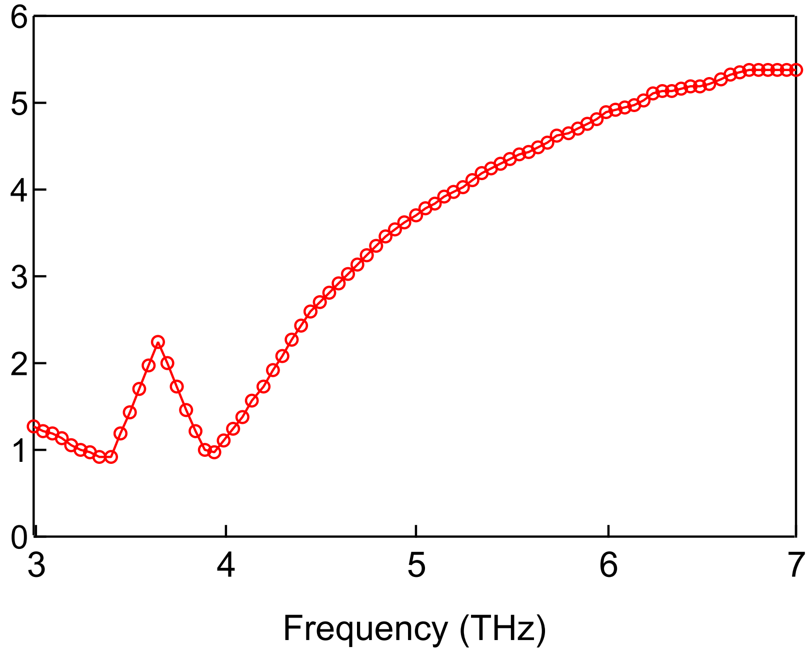
- Photo induced optical conductance

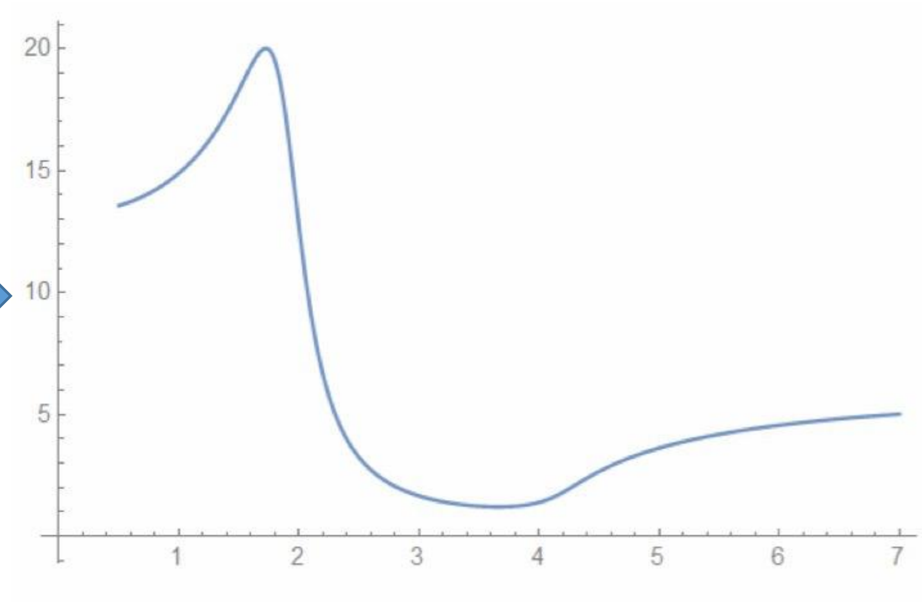
$$\tilde{E}_{exc}(\omega)/\tilde{E}_0(\omega) = (1+n)/(1+n+Z_0\Delta G)$$

$\tilde{E}_{exc}(\omega)$ is the complex fourier amplitude of the sample signal.
$\tilde{E}_0(\omega)$ is the complex fourier amplitude of the reference signal.
n is the complex refractive index of the sample.
Z_0 is the impedance of free space.
ΔG is the transient photoinduced optical conductance.

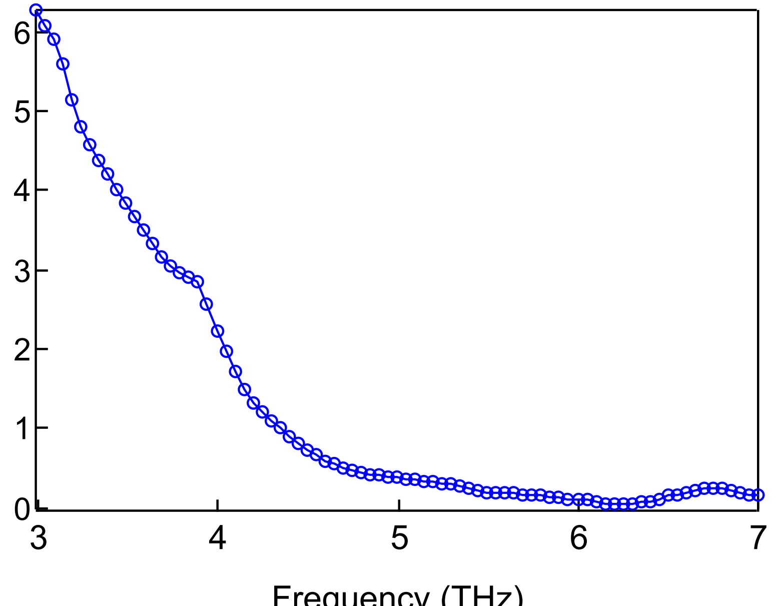
Refractive index (Exp. & Lorentz model)

Real





Imaginary



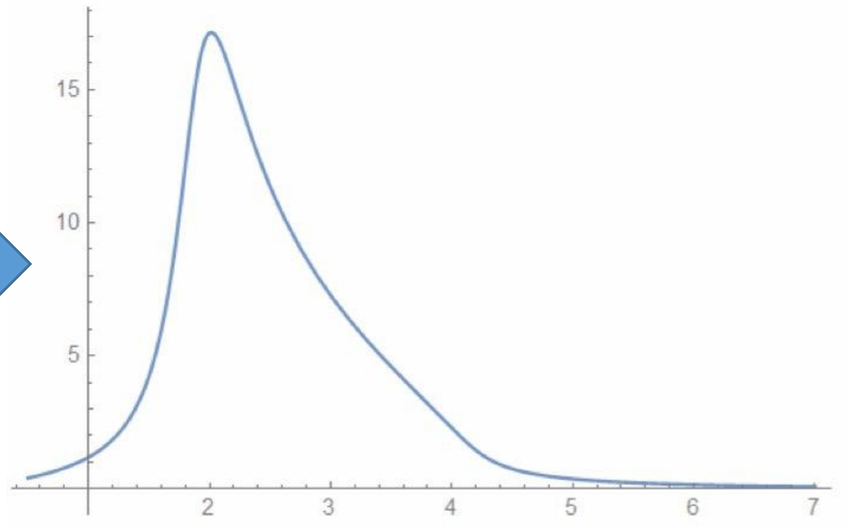
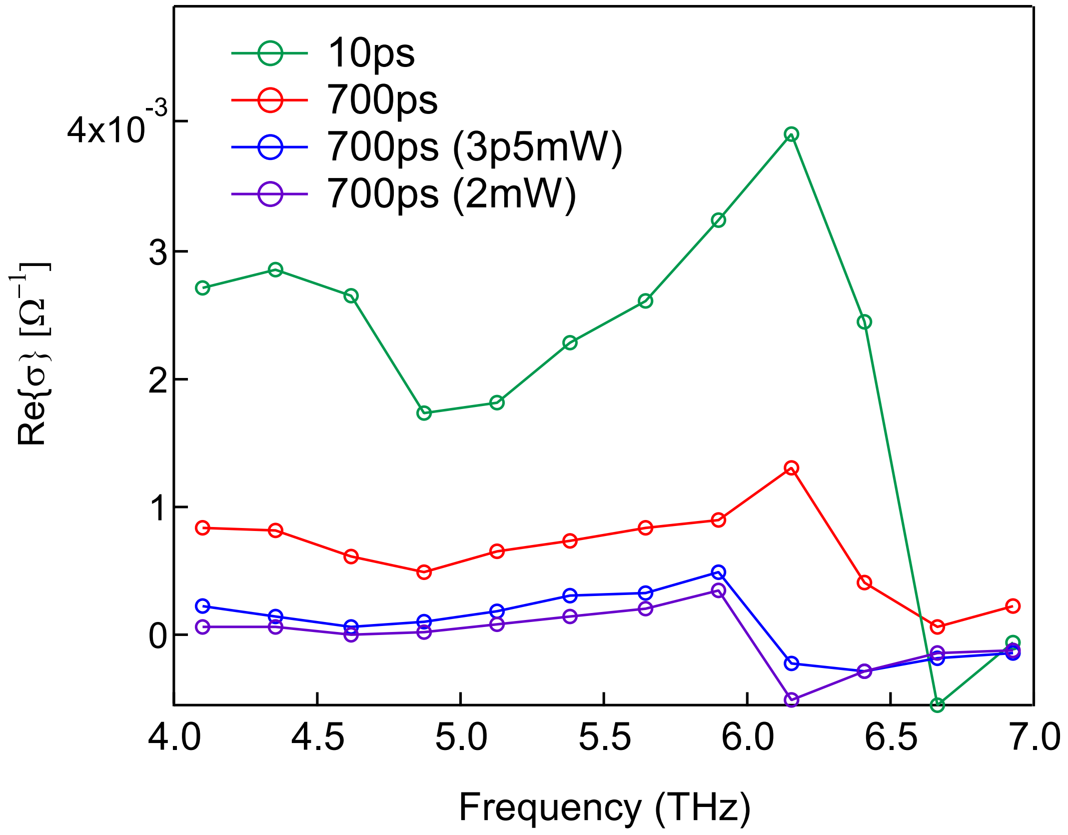
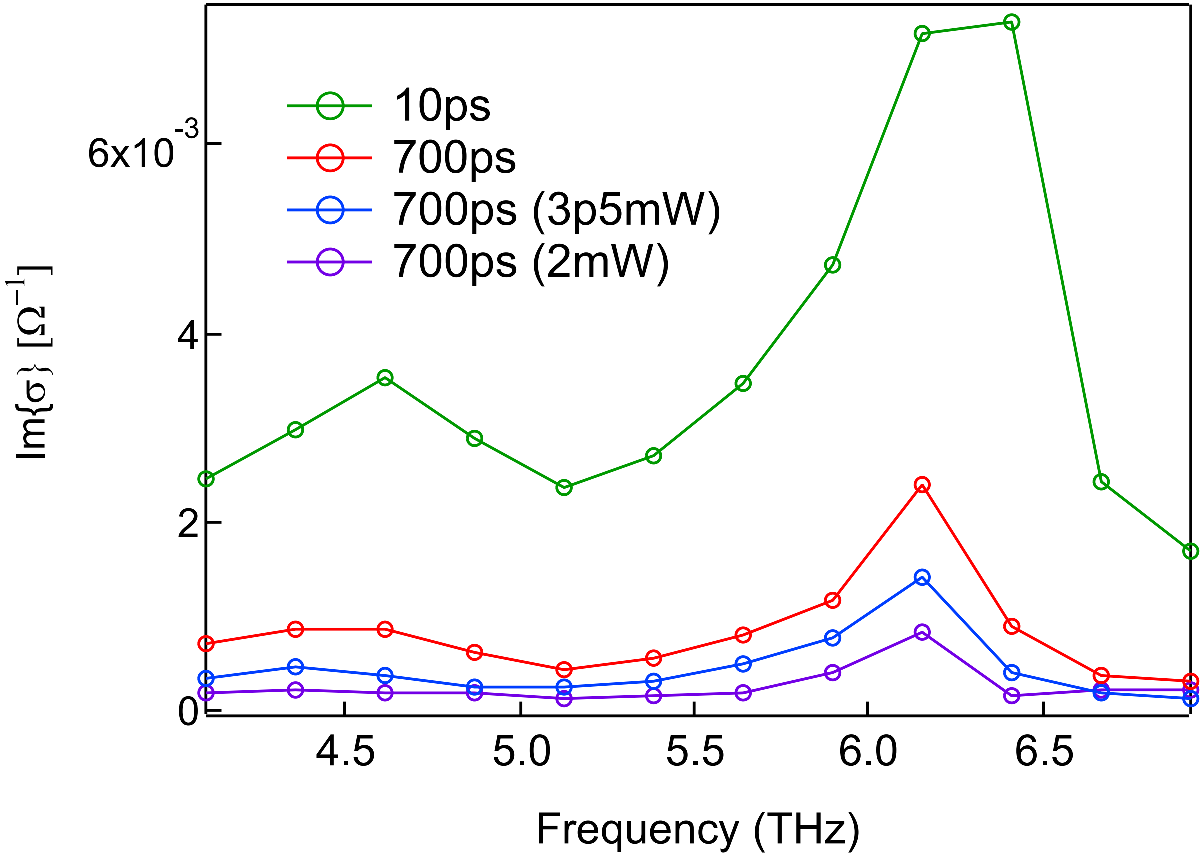


Photo induced optical conductance





The photo-induced conductance fits the Drude model!
However,sampe thickness~6μm, which is not very accurate!!!
The assumption of internal reflection is also not accurate, which effects the shape of the spectrum!

Sumarry

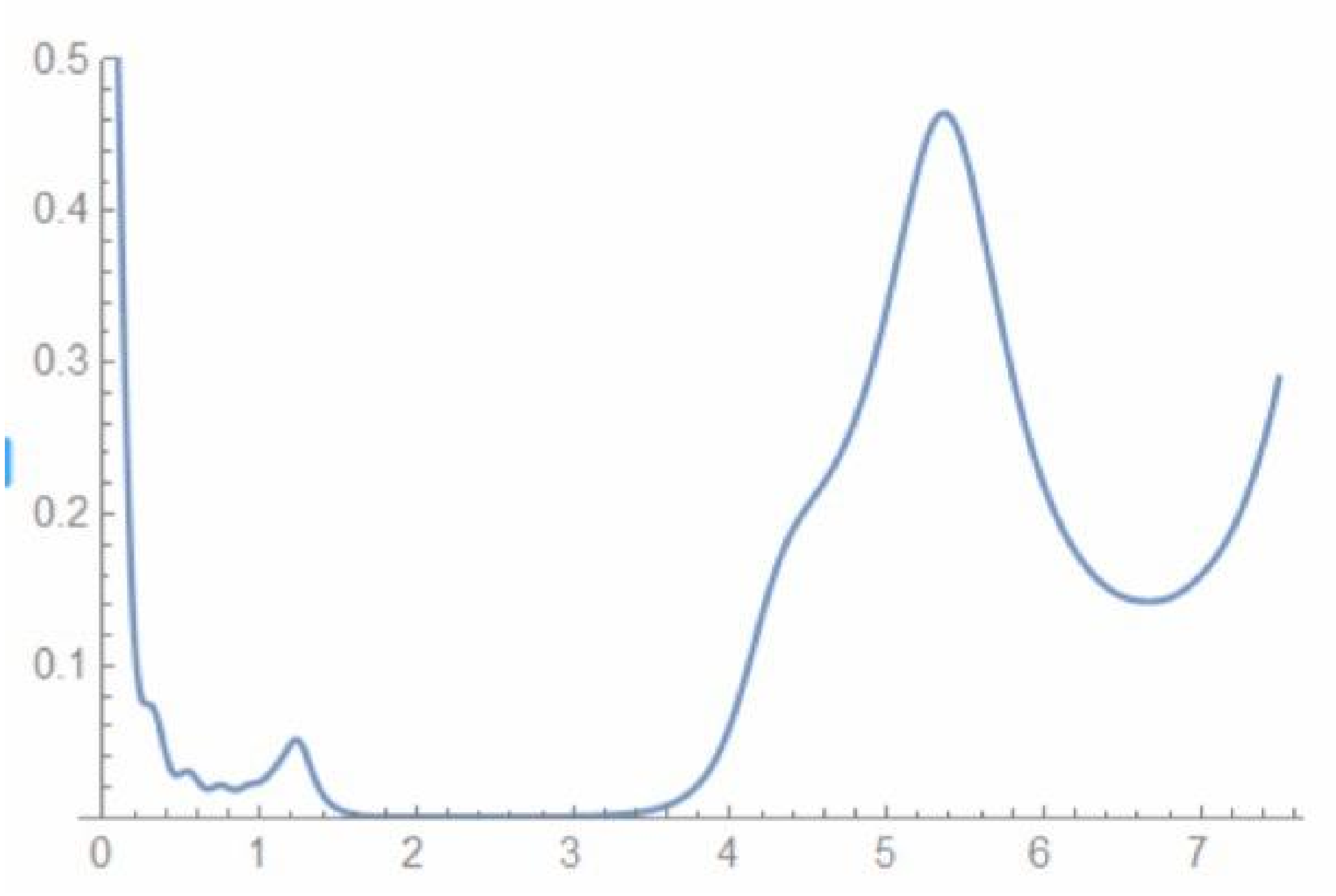
- BSTS has a long life time in the surface state.
- Above gap pump perform Bulk to Bulk excitation, below gap pump perform Bulk to Bulk excitation, and surface to surface excitation.
- The photo-induced conductance of BSTS fits the Drude model, and propably the scattering rate and plasma frequency can be extracted.

Future plan

- Extract the photo-induce conductance
- Calculate the plasmon frequency and scattering rate

→ Explain the model better

Transmittance (Lorentz-model)



Calculation ΔT/T
Lorentz-model (bulk)
+ pump induced surface conductivity (σ ~ 0.003)