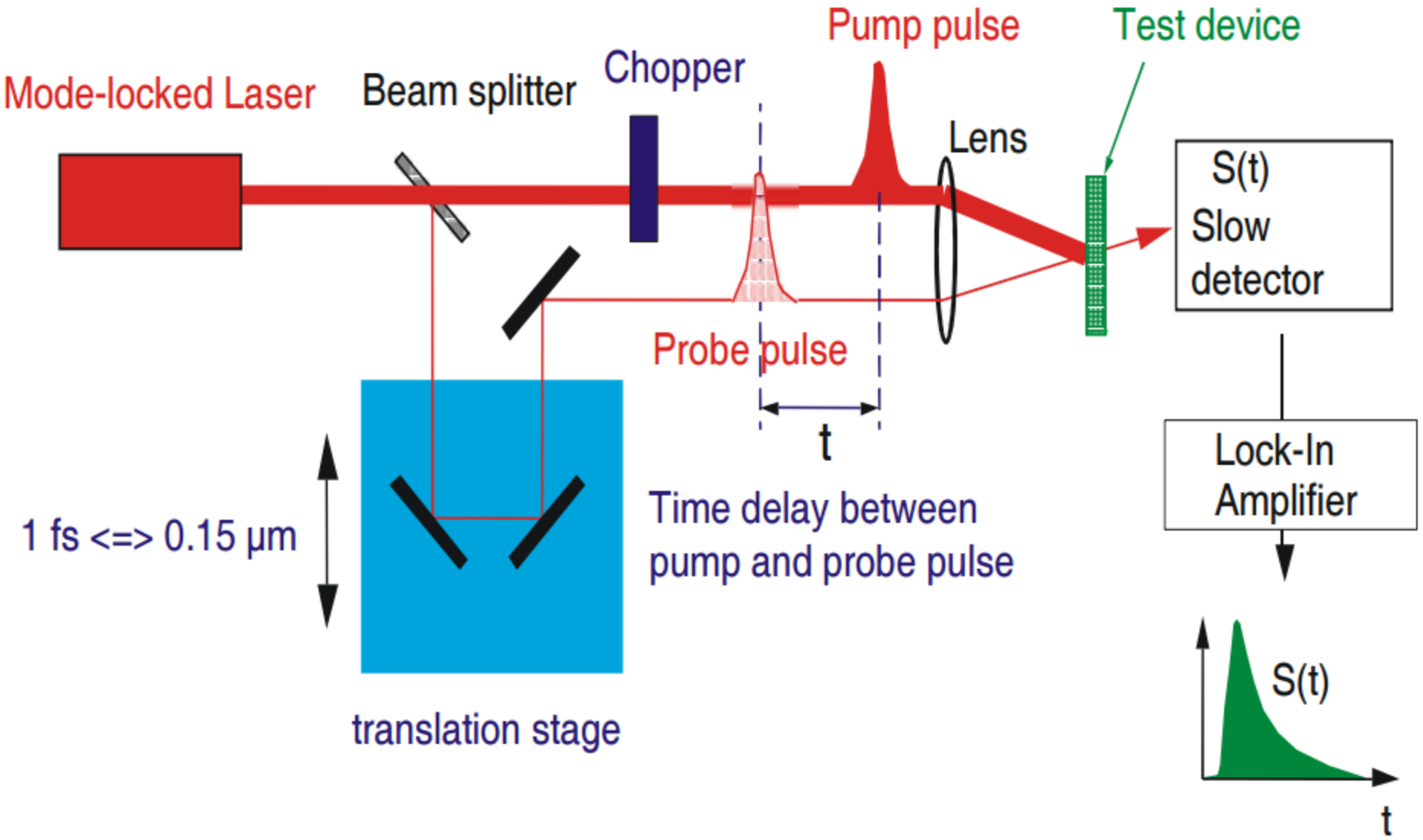
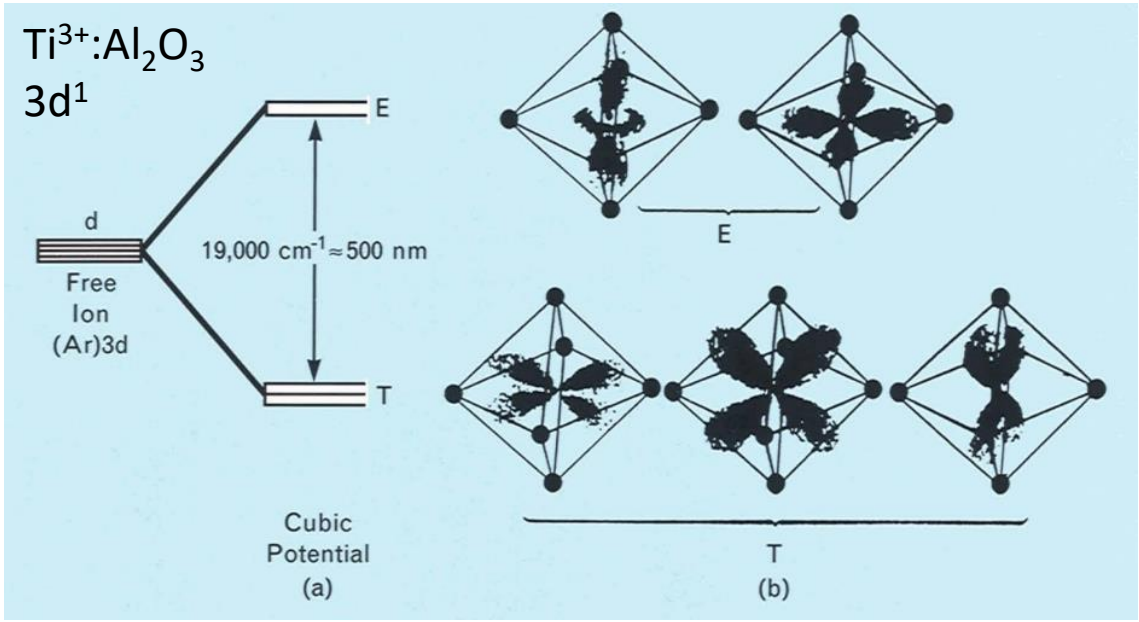
Time-resolved spectroscopy

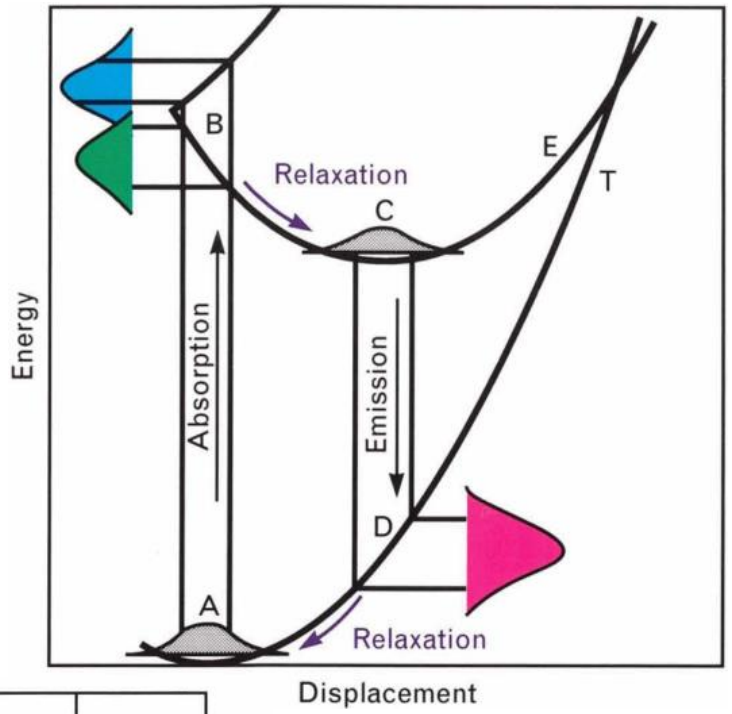
Time-resolved absorption/reflectivity/luminescence ...

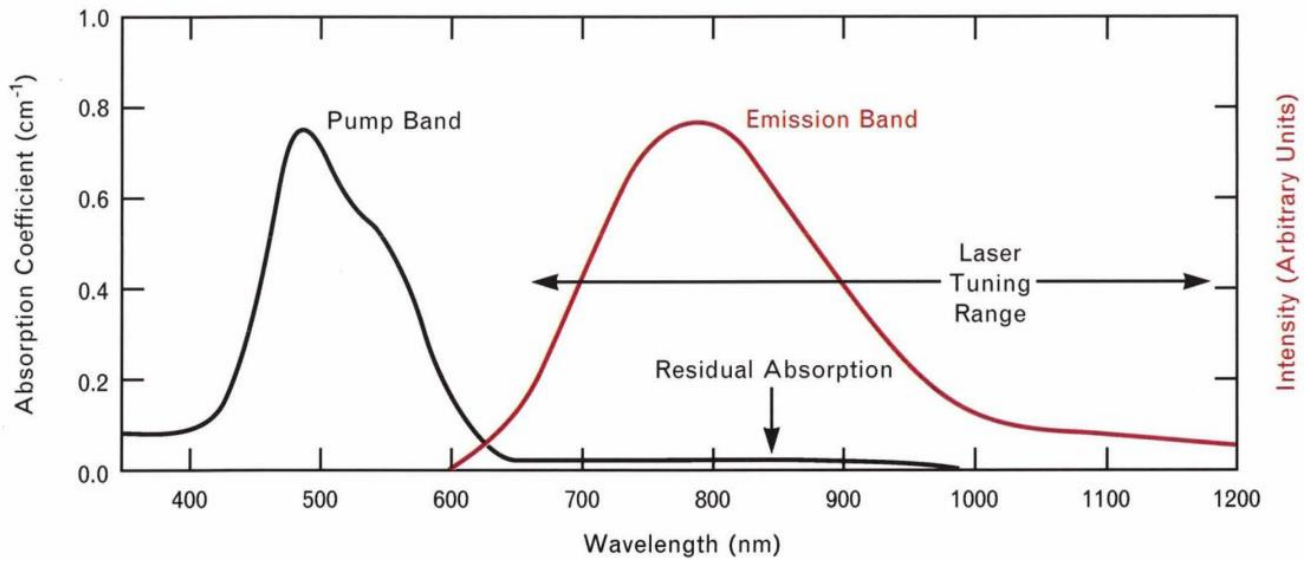


U. Keller ETH, Zürich

Ti:sapphire LASER

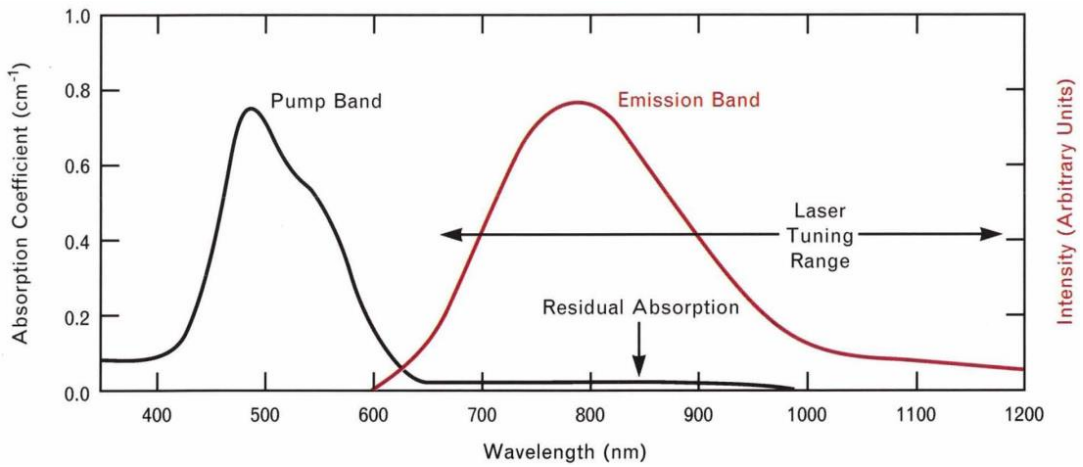




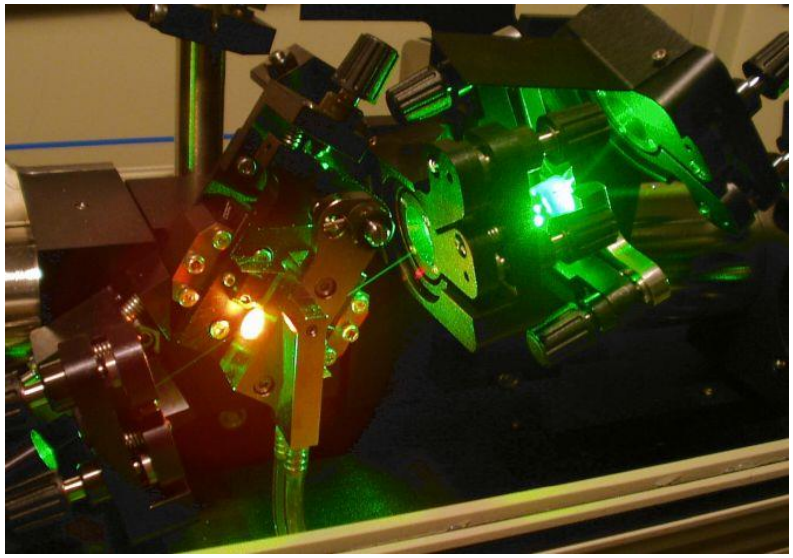


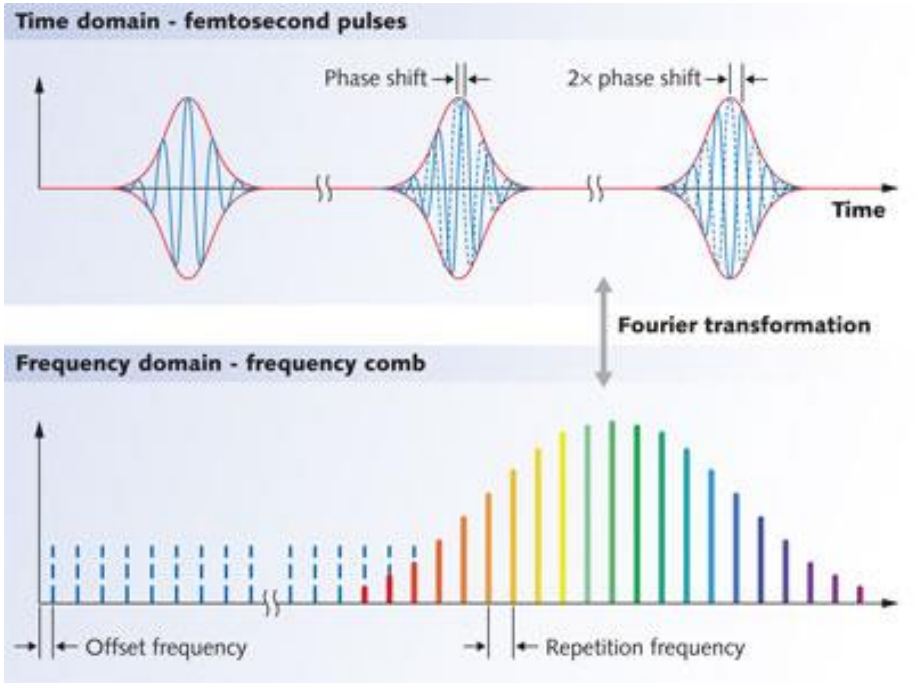
K.F. Wall and A. Sanchez. The Lincoln Laboratory Journal, 2 447 (1990)

Ti:sapphire LASER



Pump: green, lasing: NIR





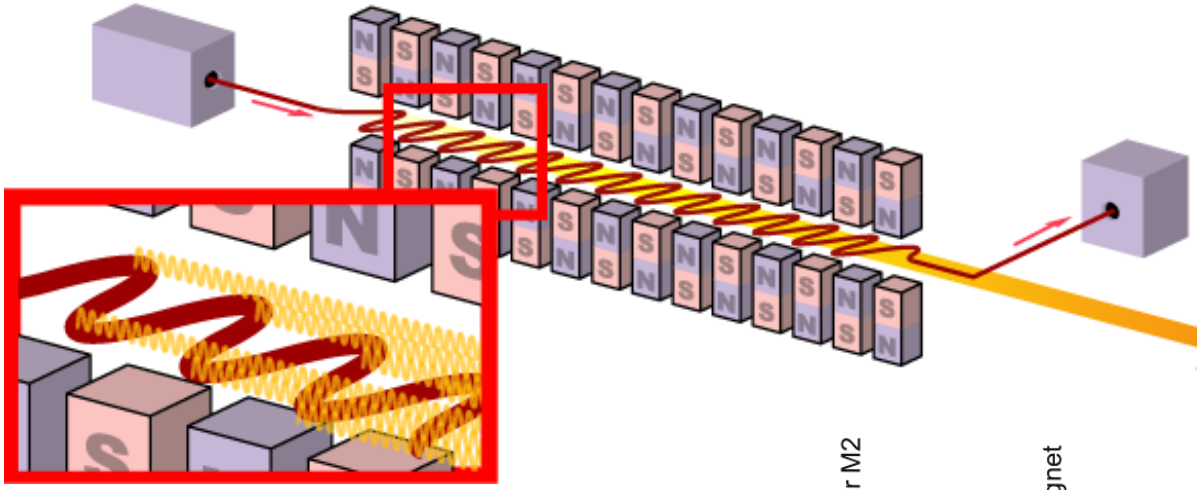
Cental wavelength: 800 nm (375 THz)
Pulse width: 10-100 fs
Repetition rate: 80 MHz ($\frac{c}{2L}$), resonantor: ~2 m

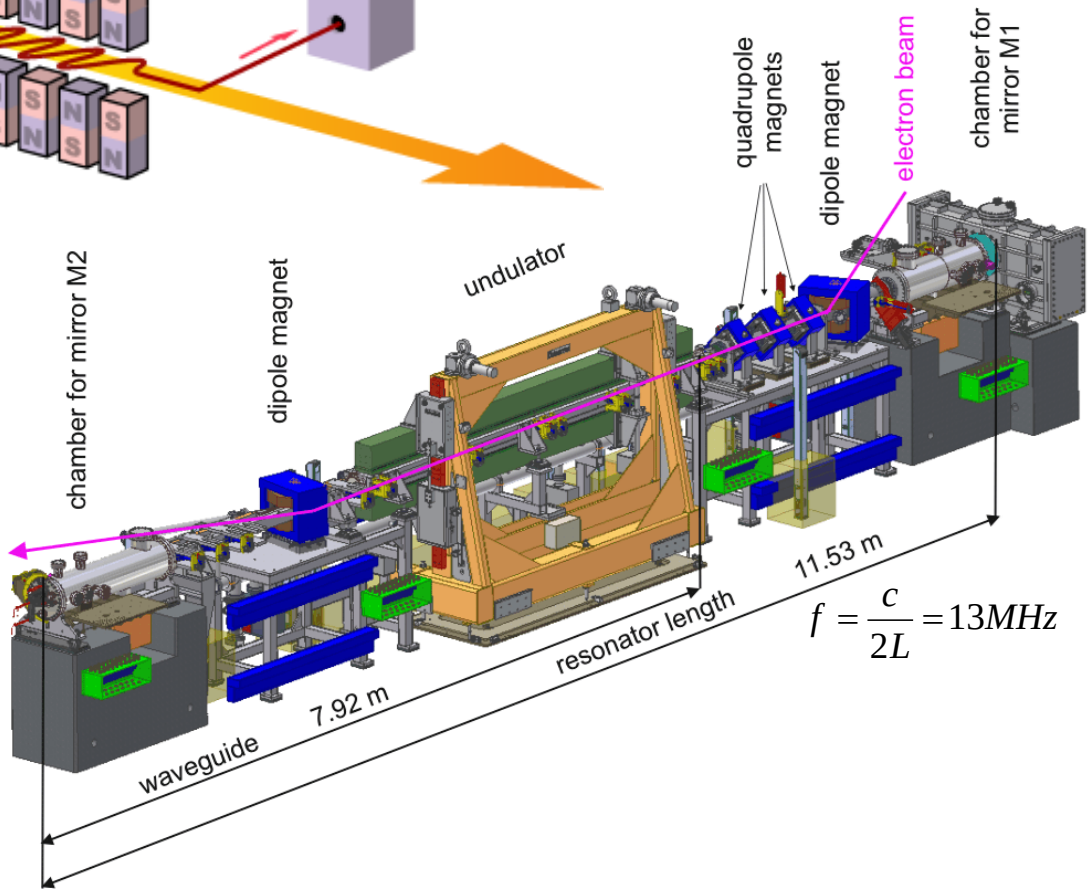
Free Electron LASER (FEL)

Lasing medium: relativistic free electrons traveling in an undulator

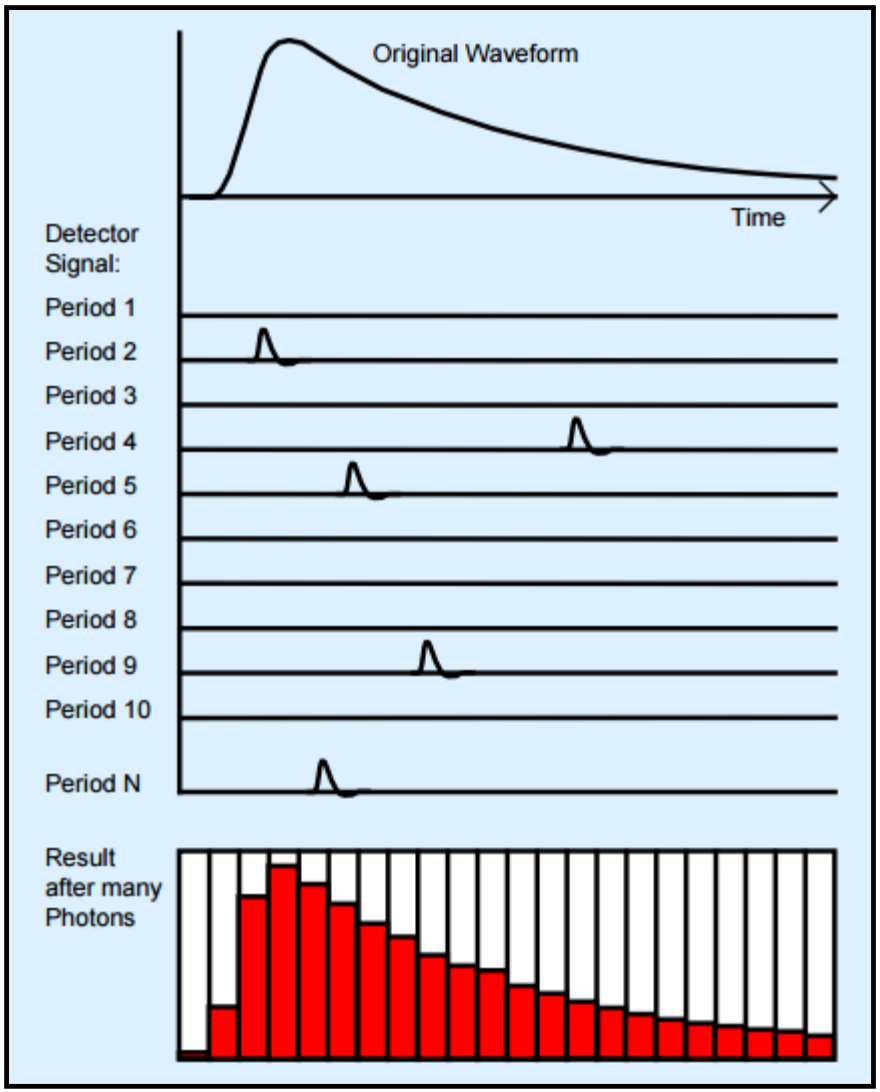
Interaction between the electron beam and the E-field of the radiation leads to bunching and coherent radiation

Most widely tuneable LASER: from microwave to X-ray





Time-Correlated Single Photon Counting



Ahmed Zewail - Facts

Ahmed H. Zewail

Born: 26 February 1946, Damanhur, Egypt

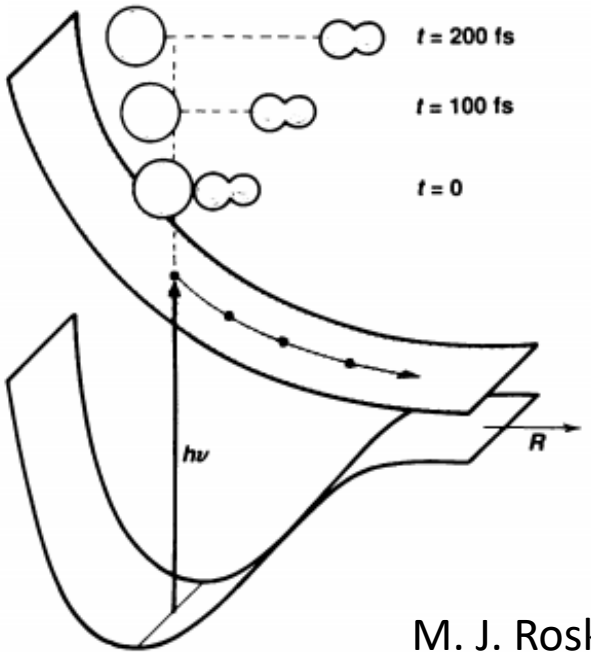
Died: 2 August 2016

Affiliation at the time of the award: California Institute of Technology (Caltech), Pasadena, CA, USA

Prize motivation: "for his studies of the transition states of chemical reactions using femtosecond spectroscopy"

Field: chemical kinetics, physical chemistry

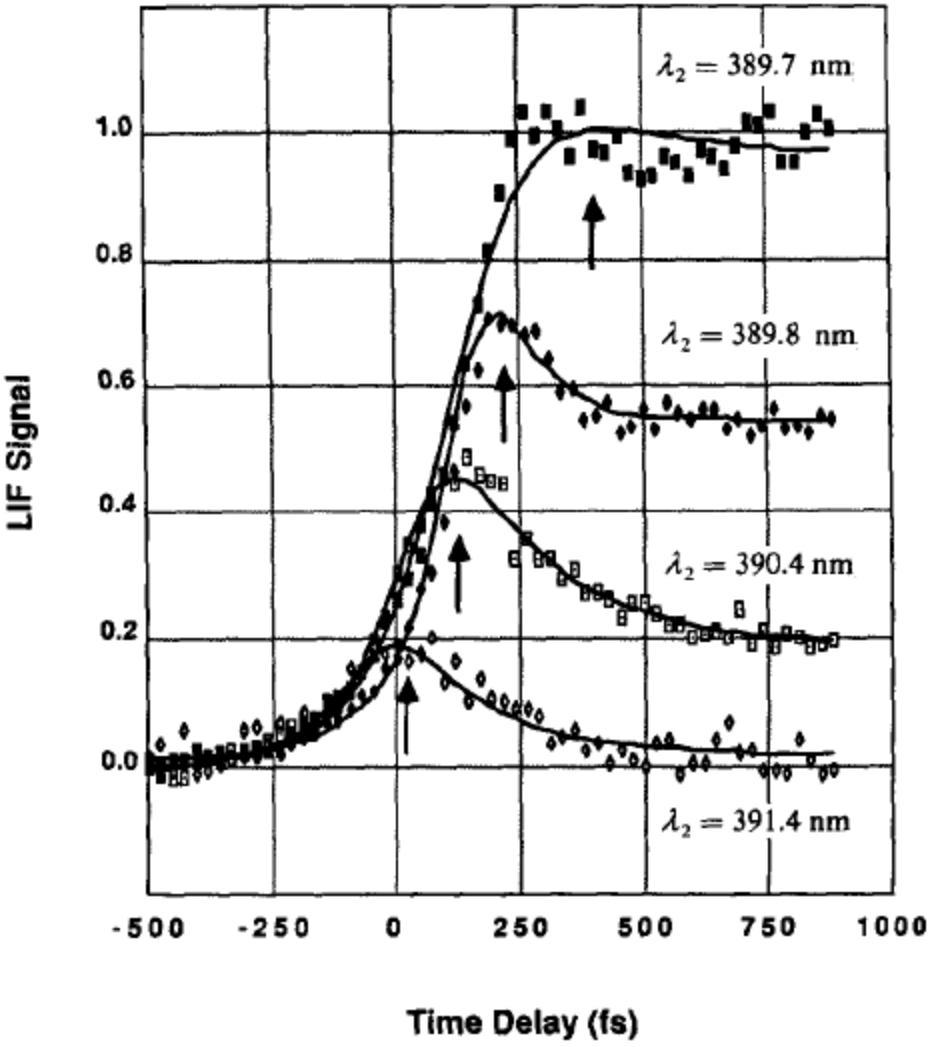
Prize share: 1/1



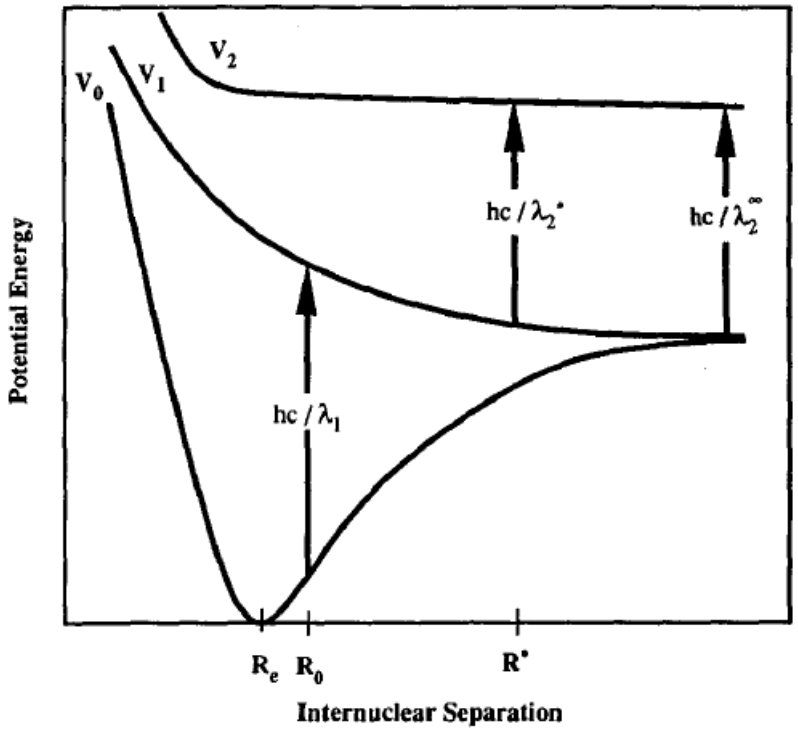
$$ICN^* \rightarrow [I \cdots CN]^{\ddagger *} \rightarrow I + CN$$

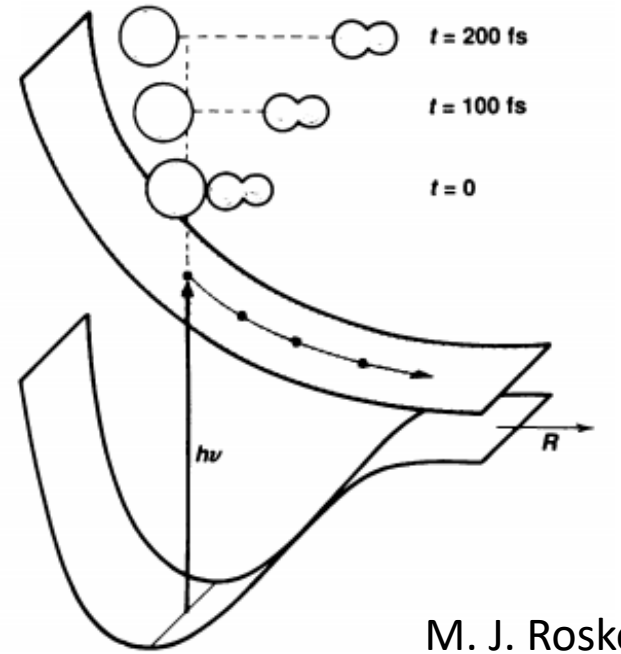
LIF: Laser Induced Fluorescence

Fluorescence signal is measured after absorption



M. J. Rosker, M. Dantus, A. H. Zewail, J. Chem. Phys. **89**, 6113 (1988).





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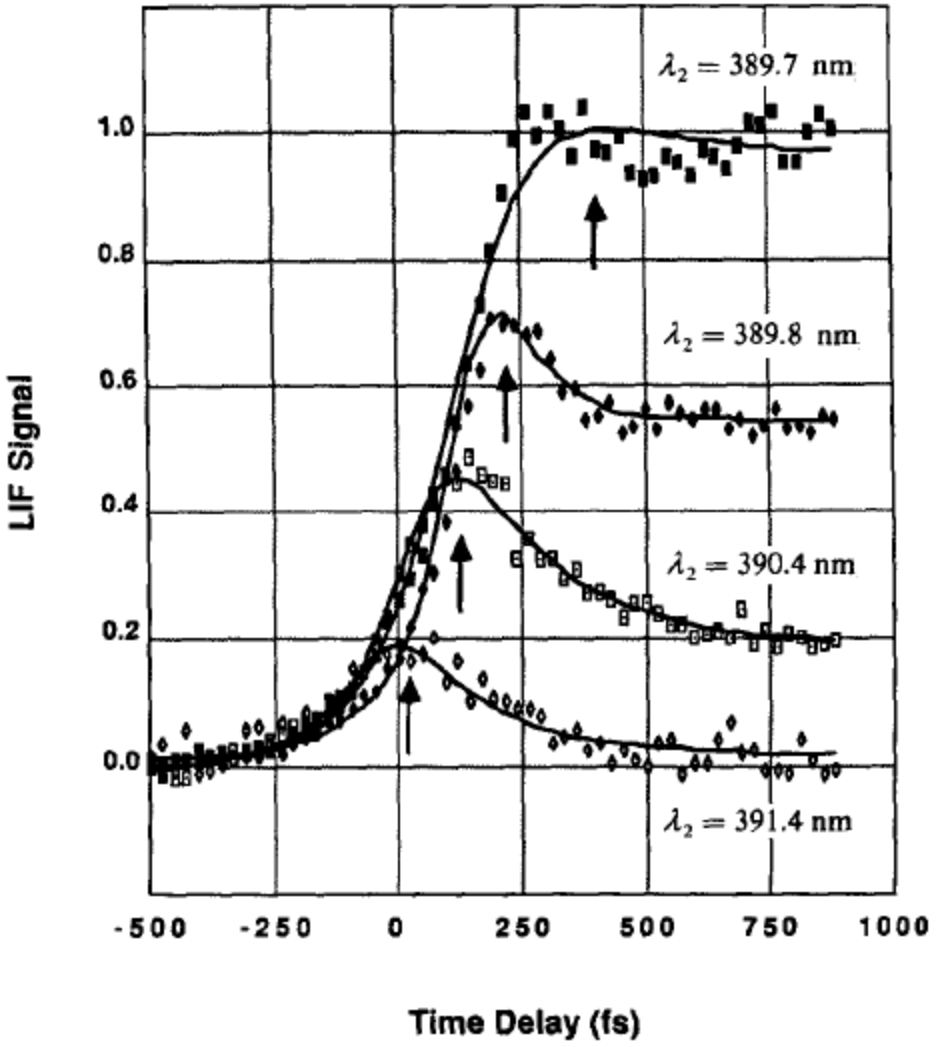
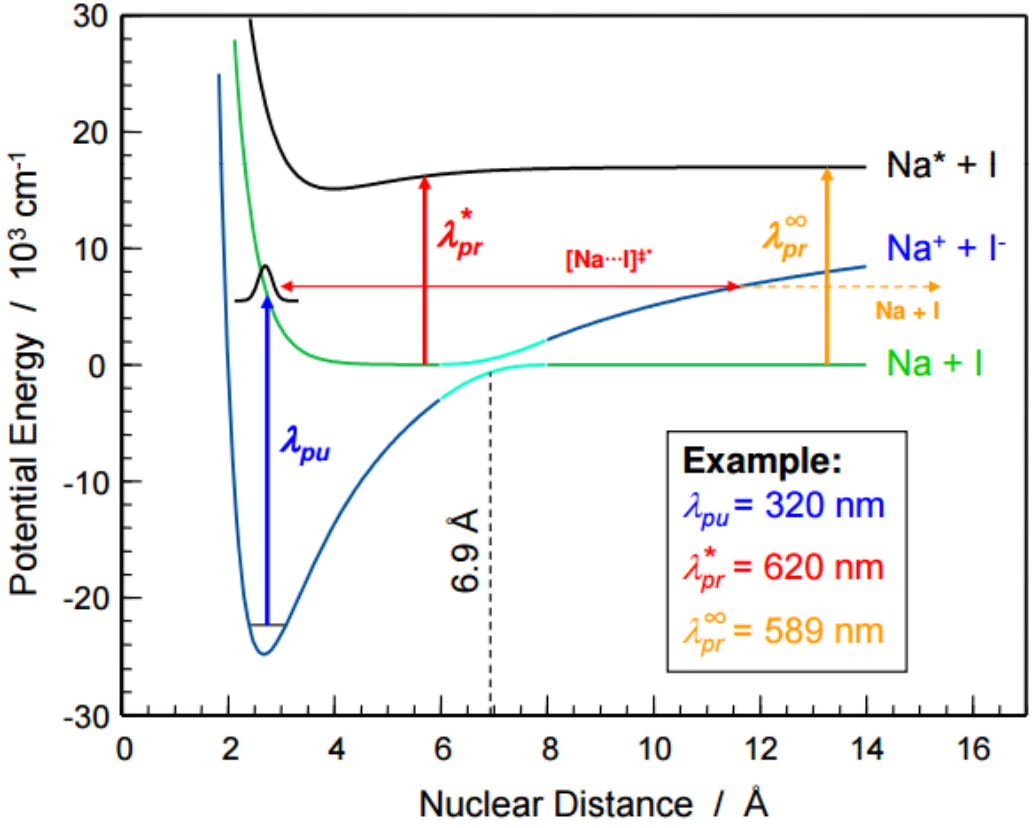
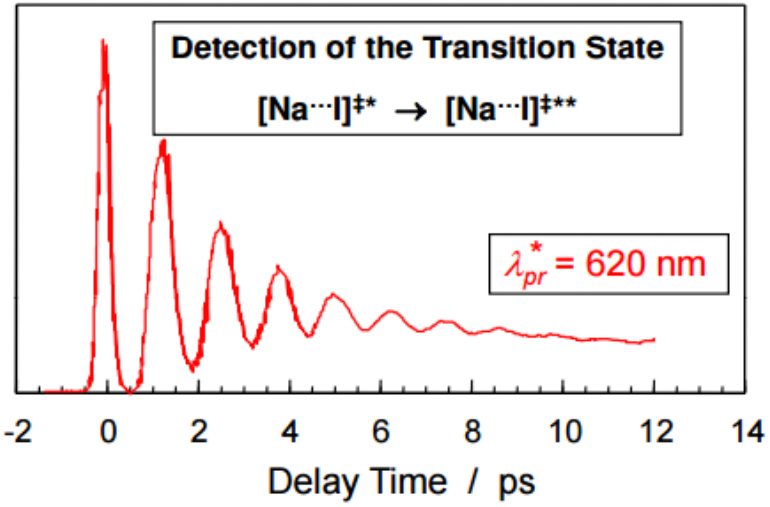
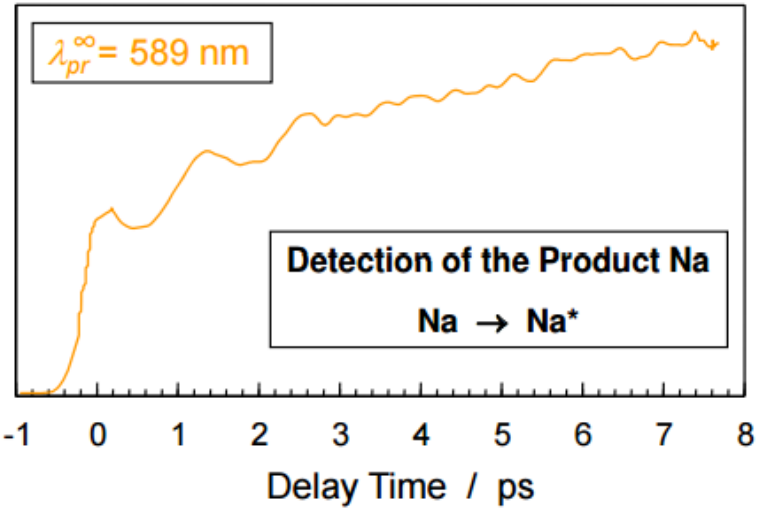


M. J. Rosker, M. Dantus, A. H. Zewail, J. Chem. Phys. **89**, 6113 (1988).



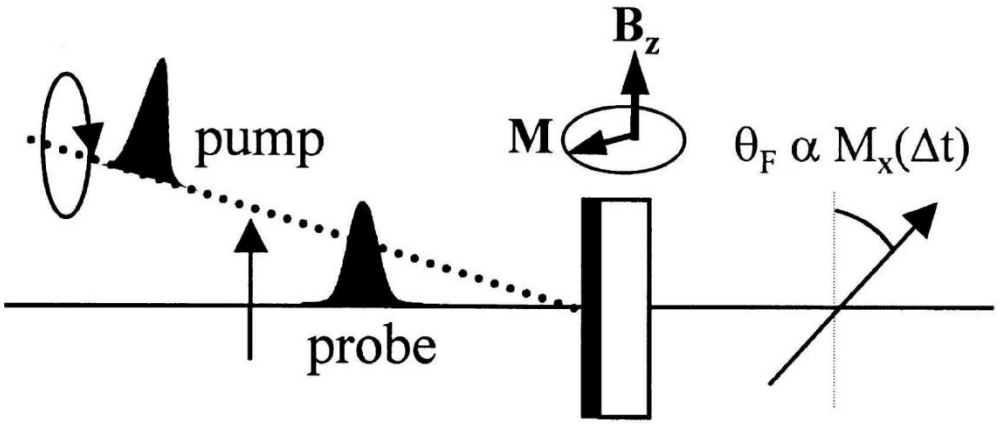




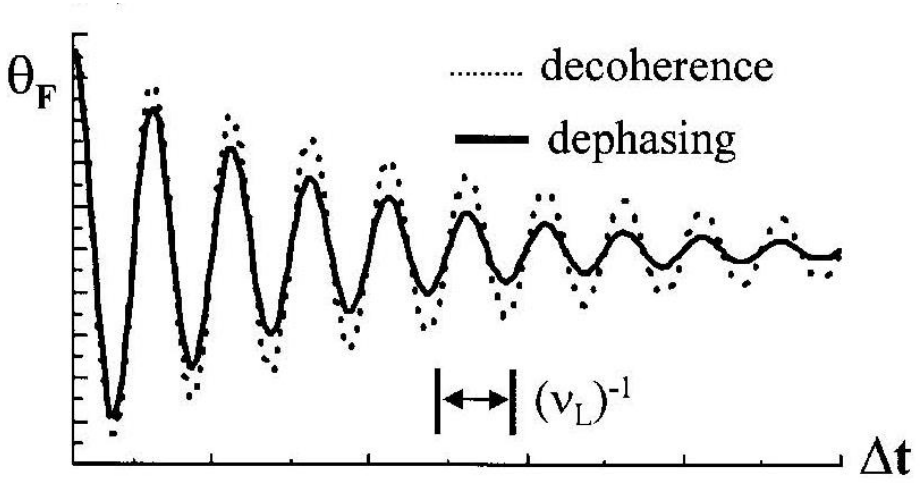
M. J. Rosker, M. Dantus, A. H. Zewail, J. Chem. Phys. **89**, 6113 (1988).

A. Materny, Jacobs University Bremen (2009).

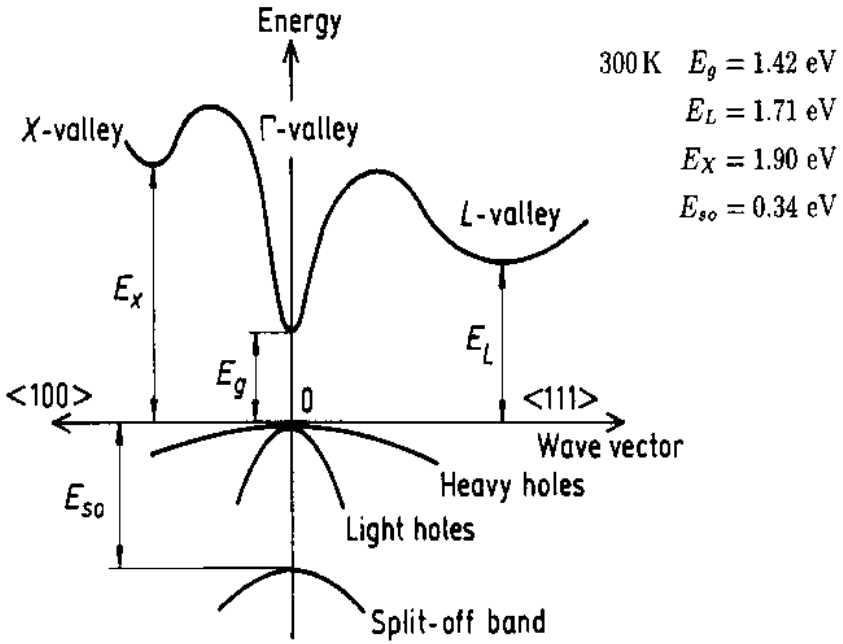
Time-domain magneto-optical spectroscopy



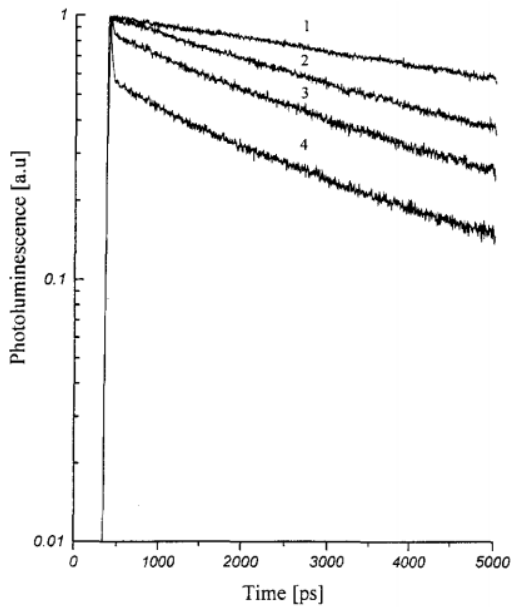
$$\theta_{\mathrm{F}}(\Delta t) = A\mathrm{e}^{-\Delta t/T_2^*}\cos(2\pi\nu_{\mathrm{L}}\Delta t)$$



J.M. Kikkawa et al., Physica E **9** (2001) 194.



300 K $E_g = 1.42$ eV
$E_L = 1.71$ eV
$E_X = 1.90$ eV
$E_{so} = 0.34$ eV



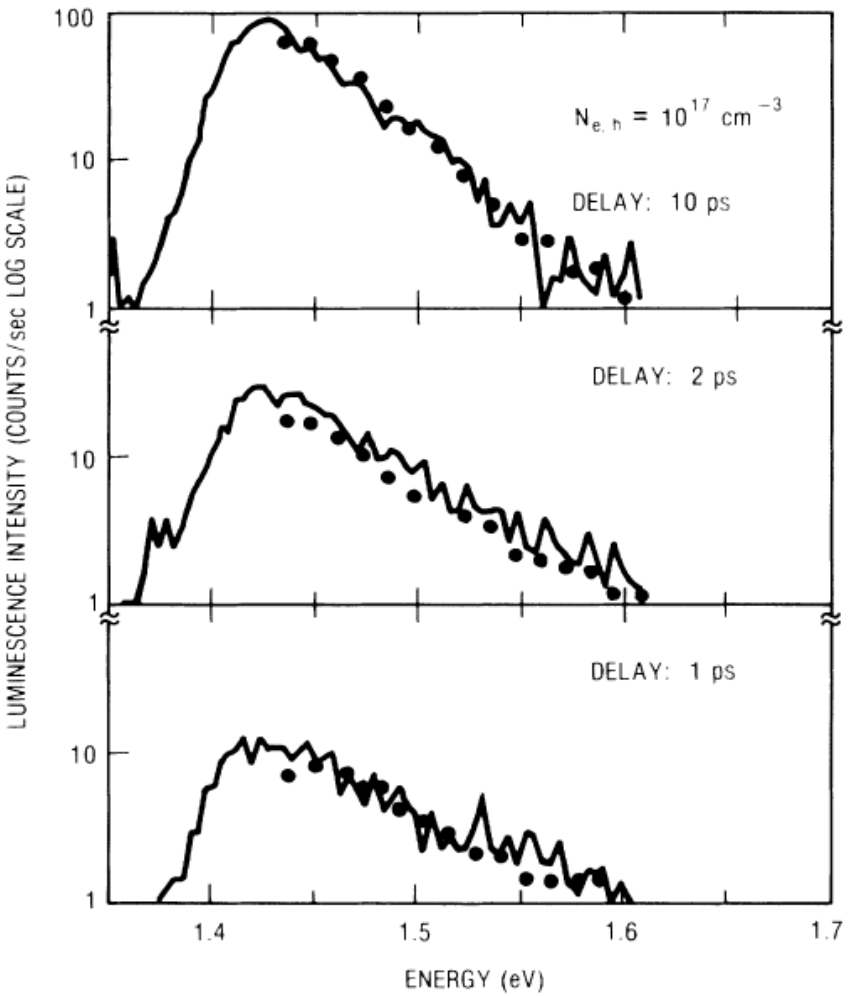


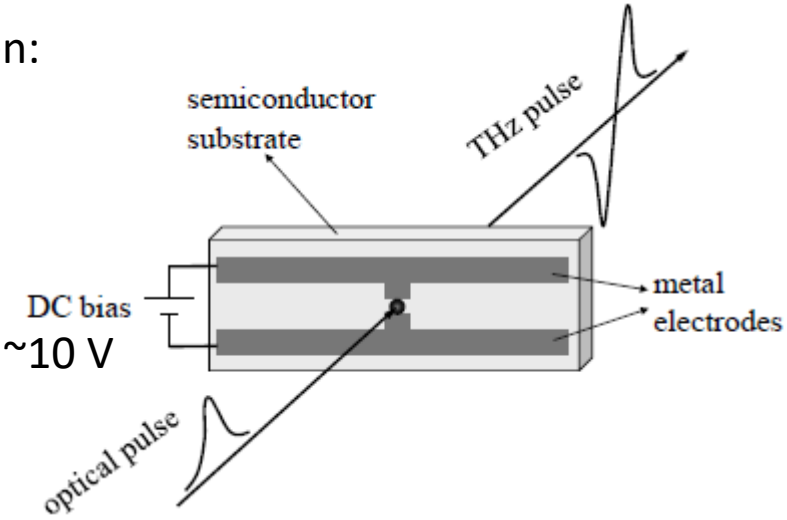
Fig. 1. Semilog plots of time resolved photoluminescence (PL) measured at various photon energies of 0.5 μm GaAs crystal. Curves 1, 2, 3 and 4 correspond to PL energy of: 1.43 eV, 1.49 eV, 1.57 eV, 1.65 eV, respectively.

Applied Surface Science 106 (1996) 457-465

J. Shah et al., Phys. Rev. Lett. (1987).

Terahertz sugárzás keltése

Dipól antenna LT-GaAs-en:



LT-GaAs:
-recombináció: τ_{rec}=0.3 ps
-mobilitás: μ=200 cm^2/Vs
(τ_{scat}=30 fs)
-gap: E_g=840 nm

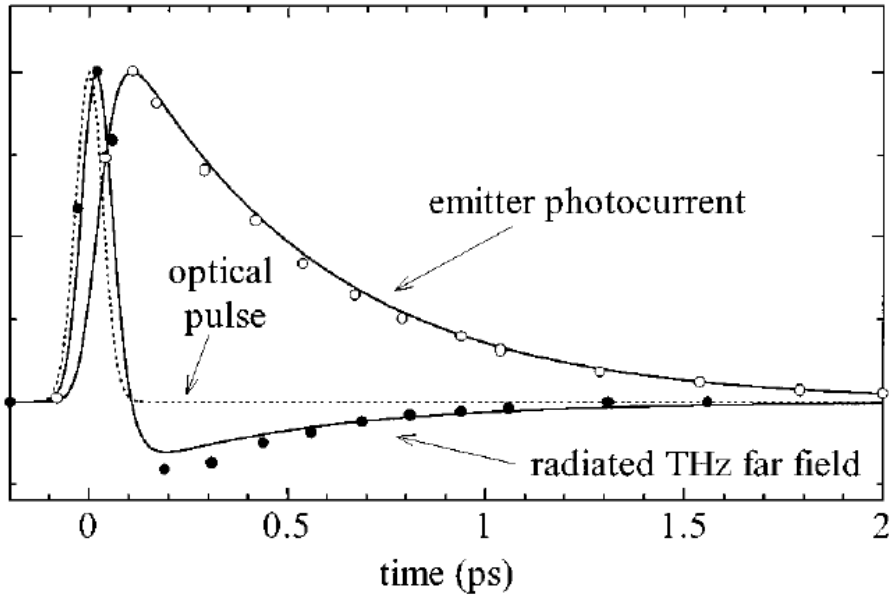
Ti:Sapphire LASER:
-központi hullámhossz: λ=800 nm
-impulzus szélesség: τ<100 fs

$$E_{THz} \propto \frac{\partial j}{\partial t}$$

$$j(t) = \int P(t-t')[en(t')v(t')]dt'$$

$$[\ldots] = e\exp(-t'/\tau_{rec})\mu(1-\exp(-t'/\tau_{scat}))\frac{V}{d}$$

$$\nu_{Max} \sim \frac{1}{\tau_{rec}} = 3 \text{ THz}$$



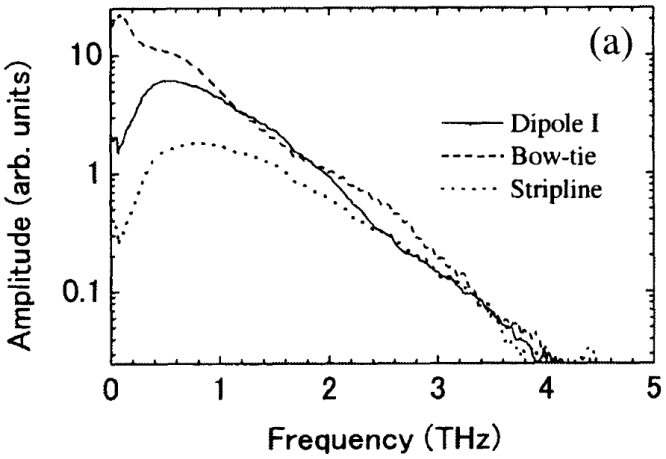
Y. S. Lee: Principles of Terahertz Science and Technology Springer, Berlin (2009)
L. Duvillaret et al. *IEEE J. Sel. Top. Quant. Electronics.* **7** 615 (2001)

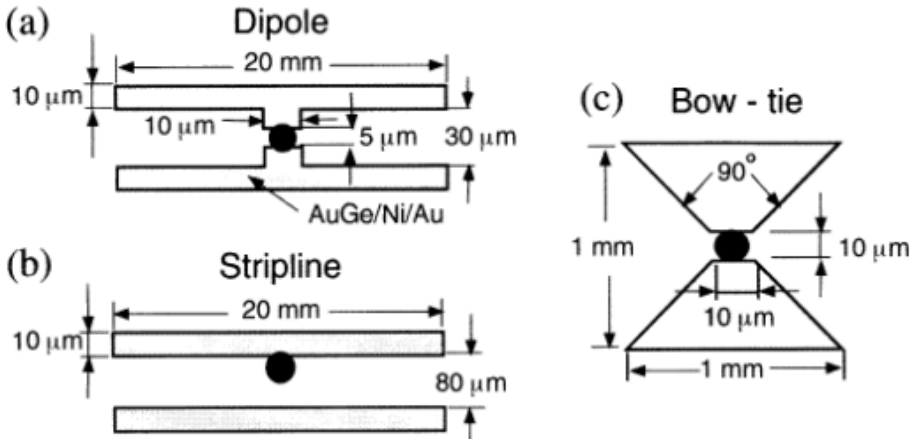
Terahertz sugárzás keltése

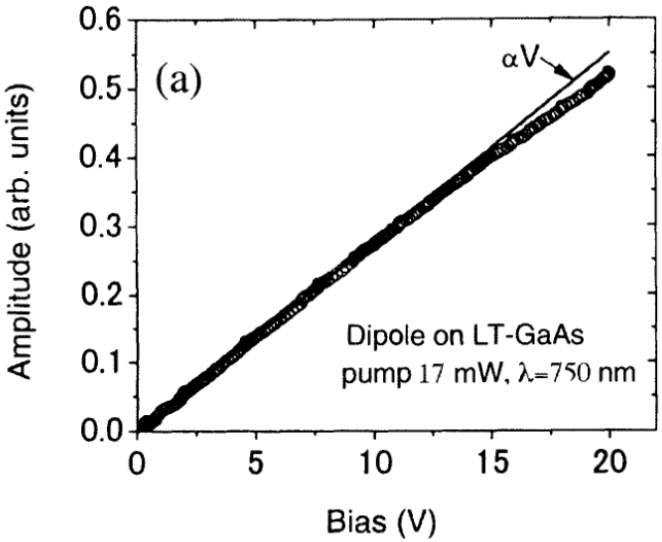
Ti:Sapphire
@ 800nm
20 mW

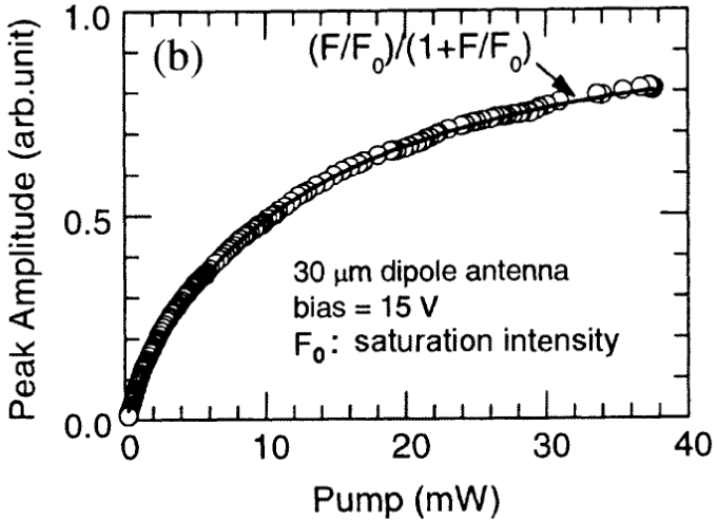
60 V →

THz sugárzás
2-3 µW





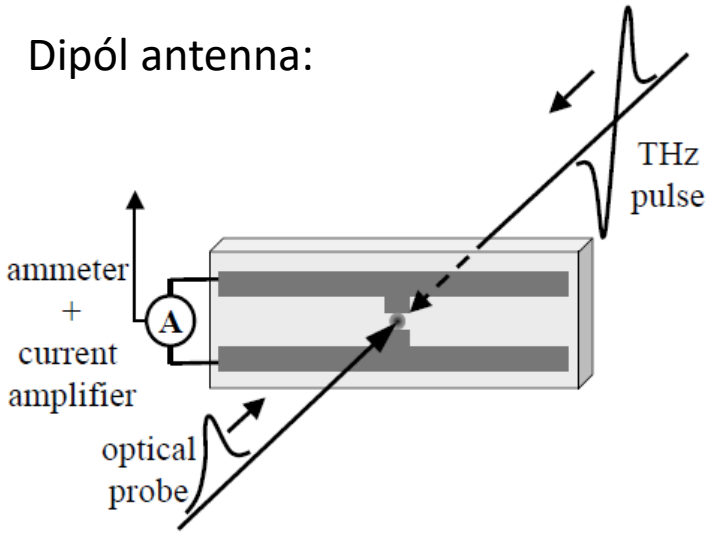




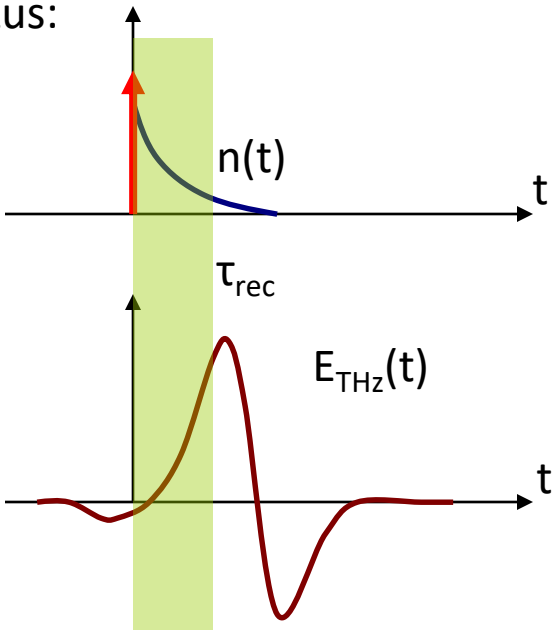
K. Sakai: Terahertz Optoelectronics Springer, Berlin (2005)

Terahertz sugárzás koherens detektálása

Dipól antenna:

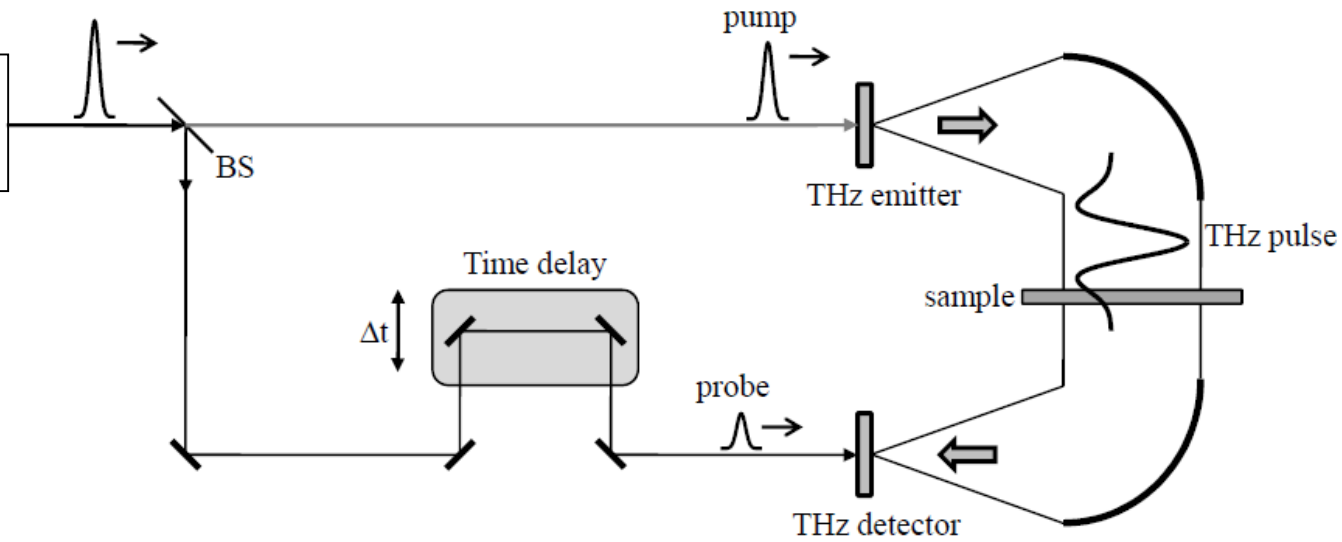


δ-impulzus:



$$j_D(t) = e\exp(-t/\tau_{rec})\int_0^t \exp(-t'/\tau_{scat})\frac{e}{m}E_{THz}(t-t')dt'$$

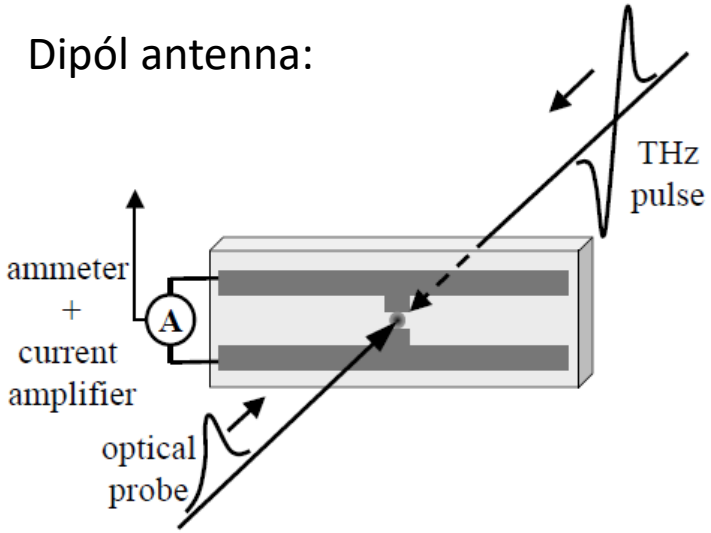
Ti:sapphire
80 MHz



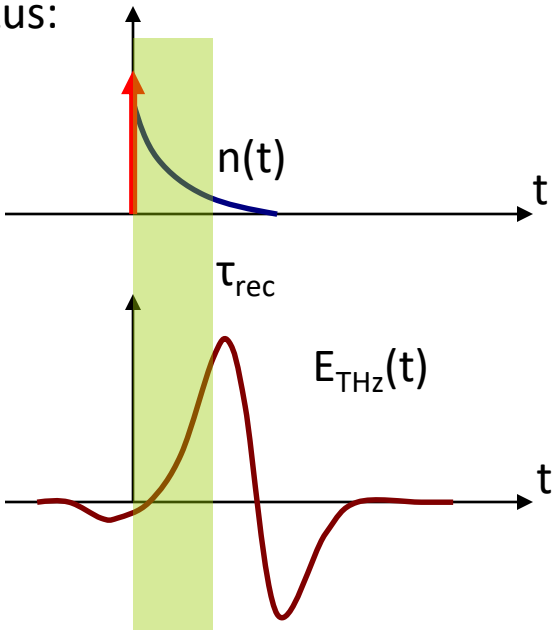
Y. S. Lee, Springer, Berlin (2009)

Terahertz sugárzás koherens detektálása

Dipól antenna:



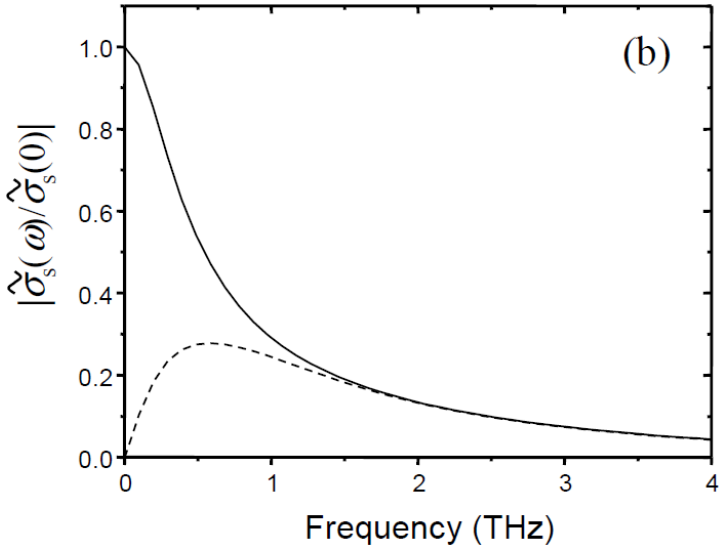
δ-impulzus:



$$j_D(t) = e\exp(-t/\tau_{rec})\int_0^t \exp(-t'/\tau_{scat})\frac{e}{m}E_{THz}(t-t')dt'$$

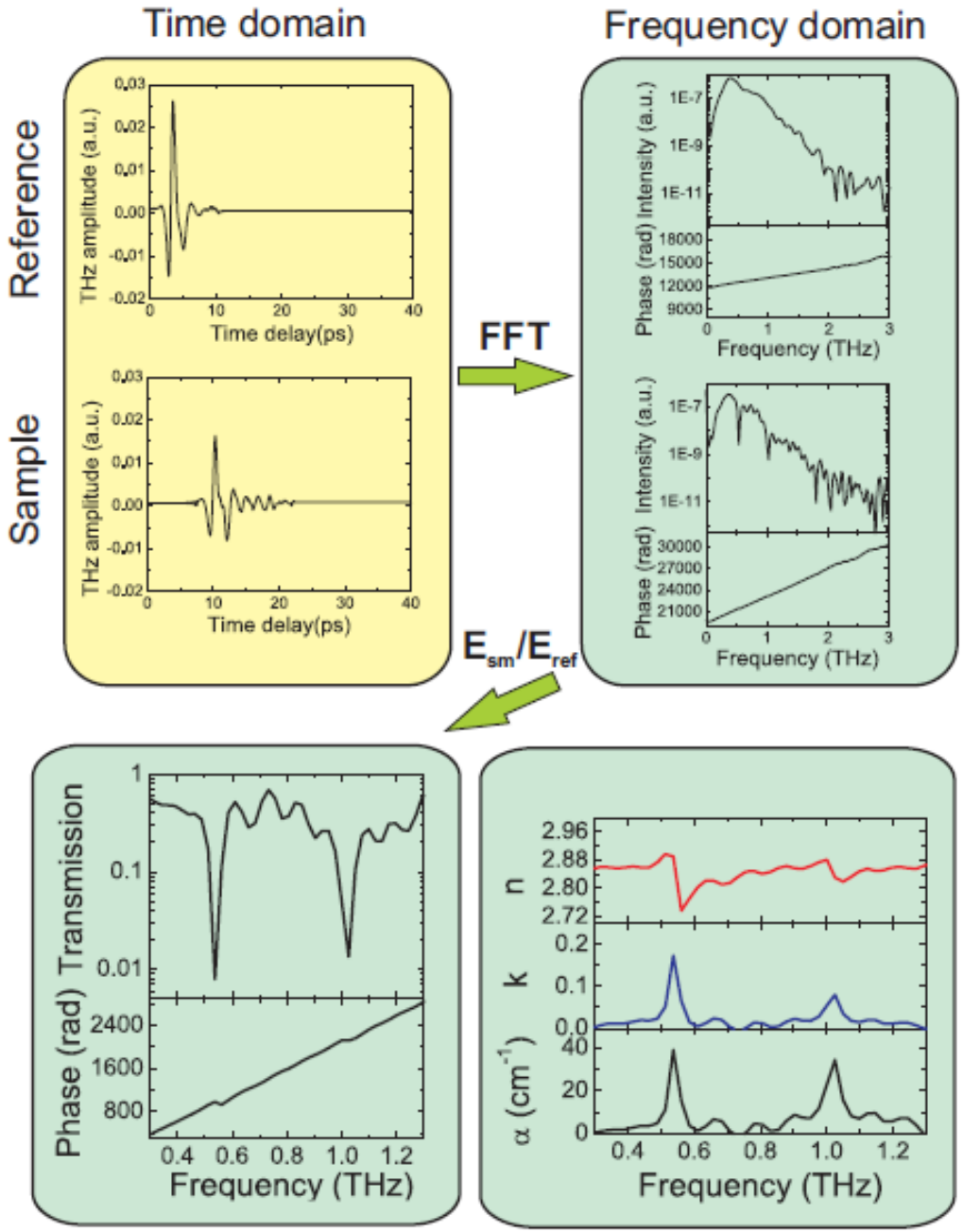
Nagy frekvenciás korlát: $1/\tau_{rec}$~3 THz

Alacsony frekvenciás limit: diffrakció limitált leképezés



Y. S. Lee, Springer, Berlin (2009)

Komplex THz spektrum

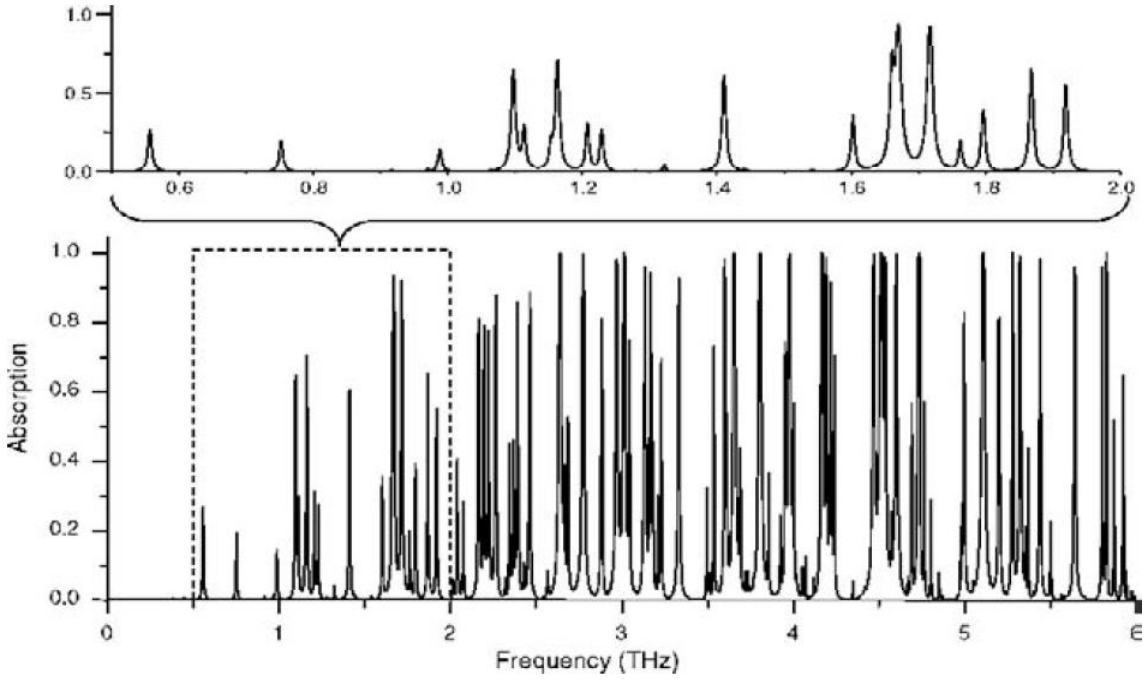


Molekulák ujjlenyomatai: rotációs spektrum

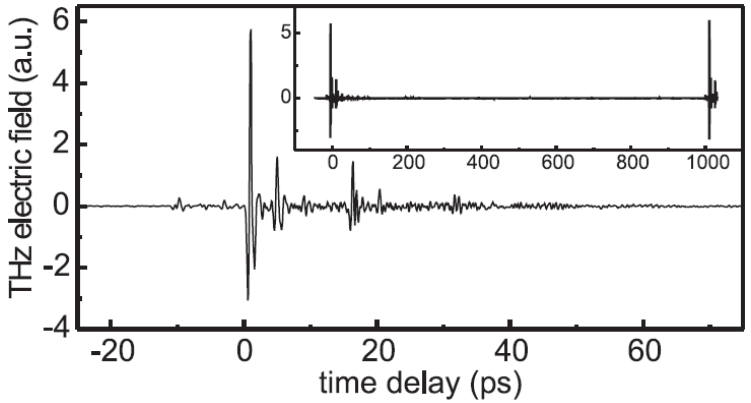
Molekulák forgási energiája:

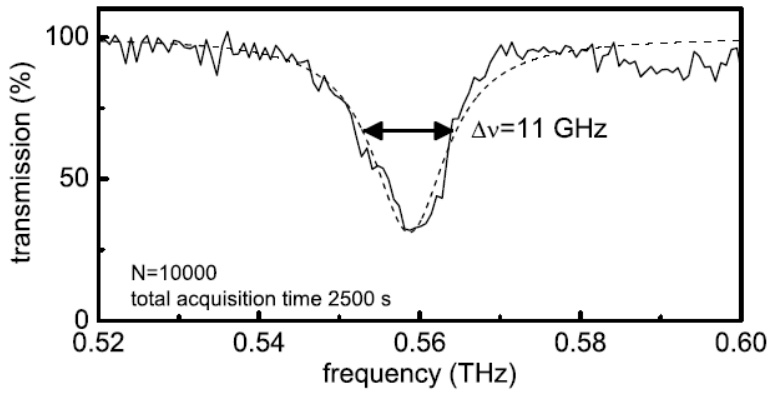
$$E \sim \frac{\hbar^2}{2MR^2} \sim 1THz$$

Víz gőz rotációs spektruma



Nagyfelbontású (~1GHz) THz spektroszkópia:

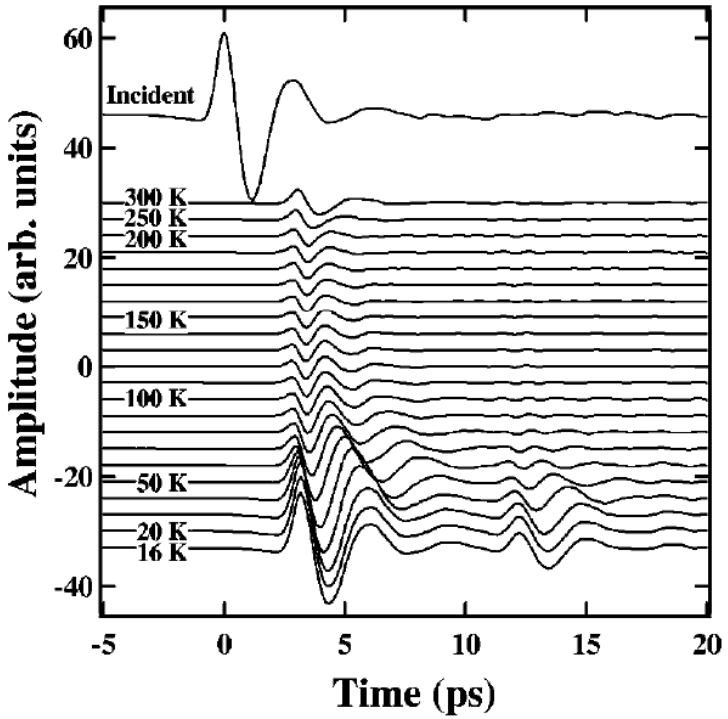


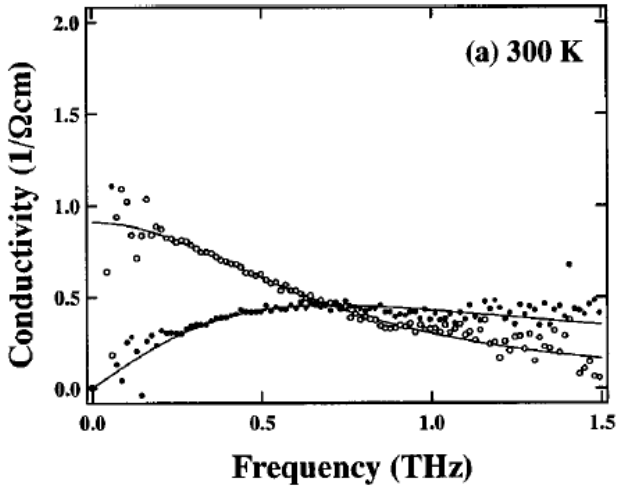


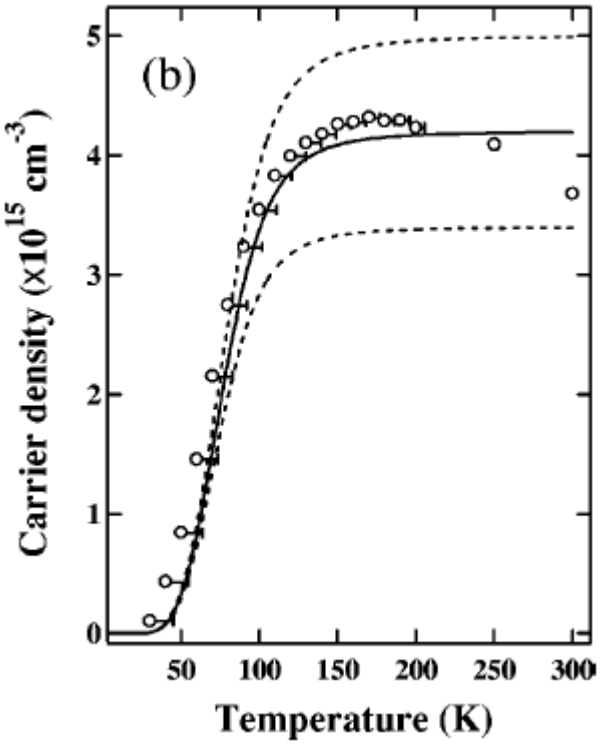
Y. S. Lee: Principles of Terahertz Science and Technology Springer, Berlin (2009)
A. Bartels et al., *Opt Exp* **14** 430 (2006)

Félvezető szeletek érintésmentes minősítése

Adalékolt p-Si szelet







$N_D=4.2\times10^{15}cm^{-3}$

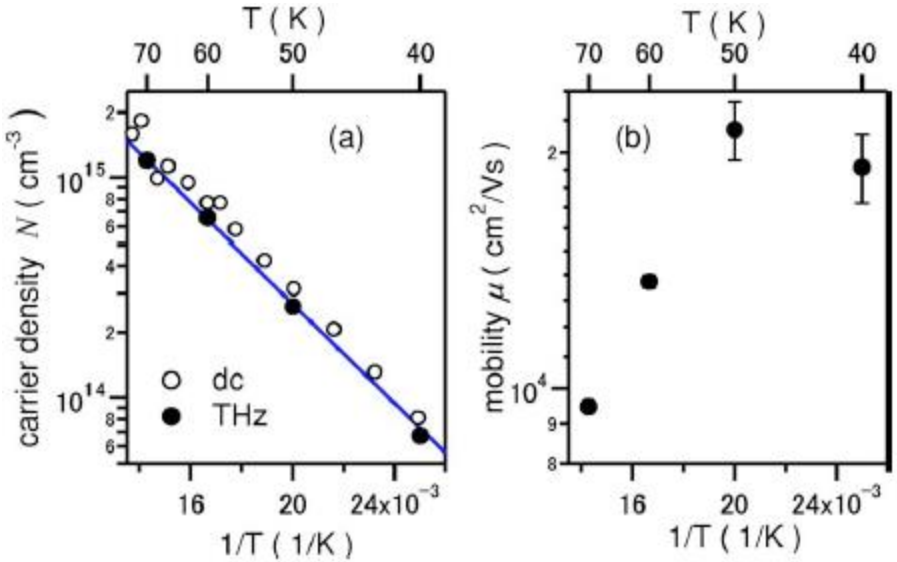
S. Nashima et al. *J. Appl. Phys.* **90** 15 (2001)

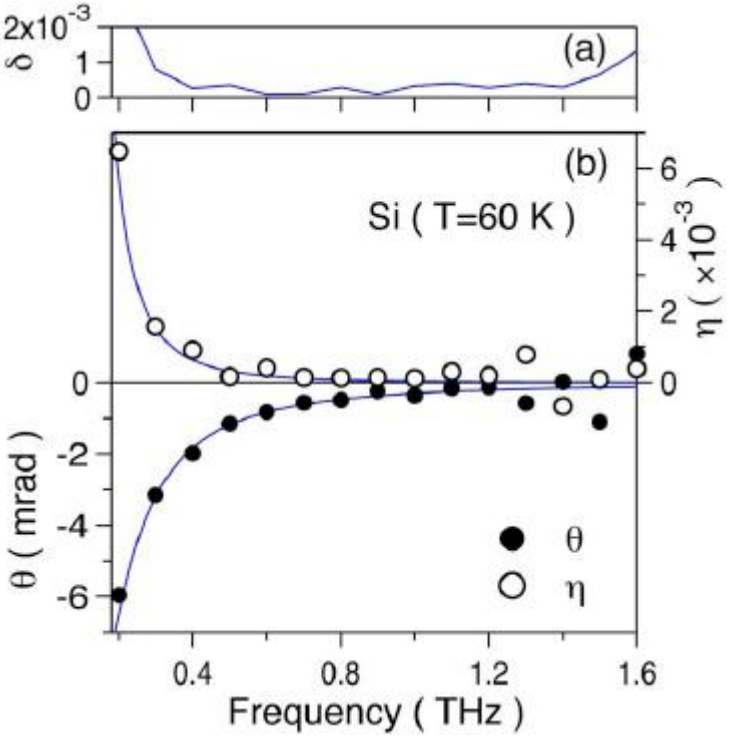
Félvezető szeletek érintésmentes minősítése

Adalékolt n-Si szelet

$$E_y(\omega,B) \approx E_0(\omega)\exp\left[-i\omega\left(t-\frac{\hat{N}(0)}{c}d\right)\right]\times(\sin\theta + i\eta\cos\theta) = E_x(\omega,0)(\sin\theta + i\eta\cos\theta),$$

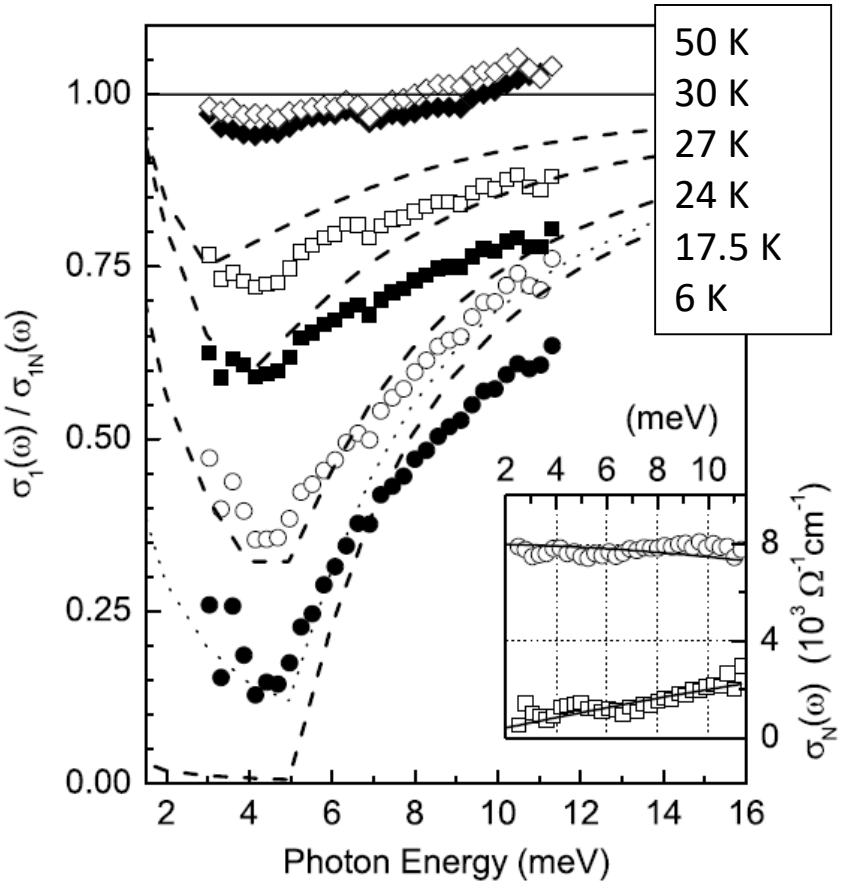
$$\theta + i\eta = -\frac{\omega}{2c}\frac{i\epsilon_{xy}}{\sqrt{\epsilon_{xx}}}d$$

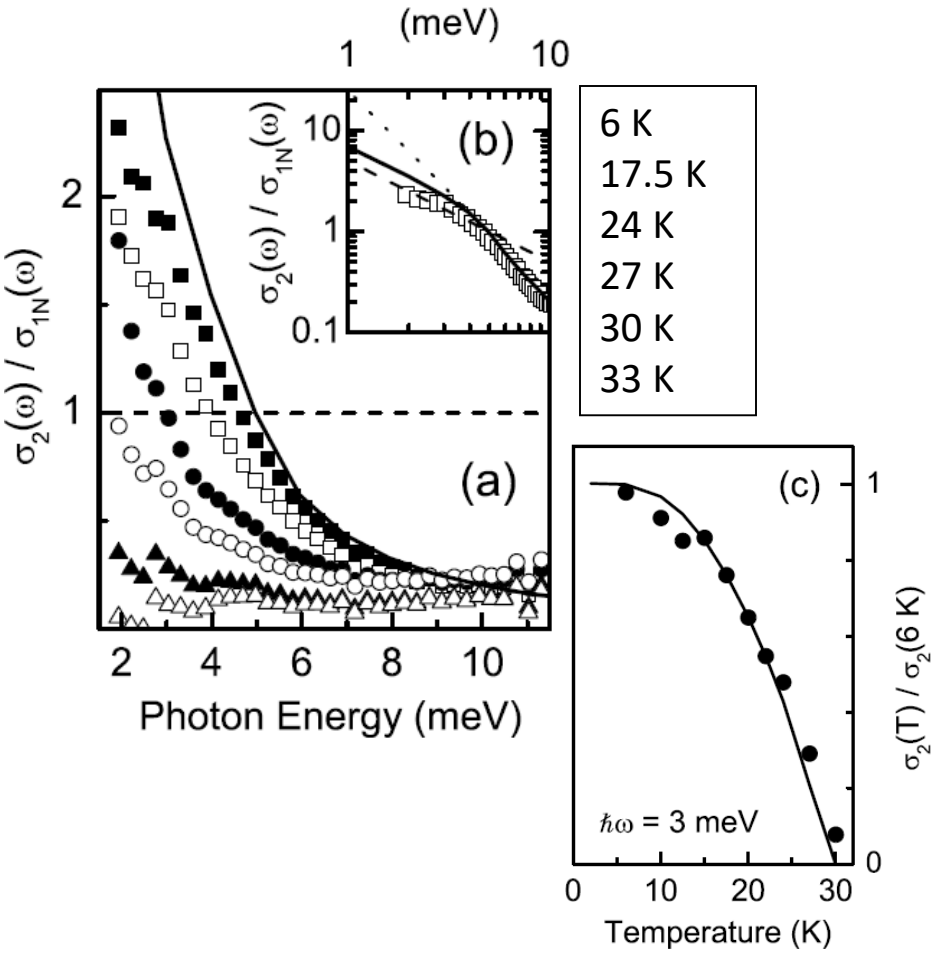




Appl. Phys. Lett. **92, 012111 2008**

Szupravezetők elektrodinamikája: MgB_2





BCS fit: $2\Delta_o$=5 meV

Gyenge csatolás: $2\Delta_o = 3.5 k_B T_C$=9 meV

Gap alatt kvázirészecske gerjesztés

R. A. Kaindl et al., *Phys. Rev. Lett.* **88** 027003 (2002)

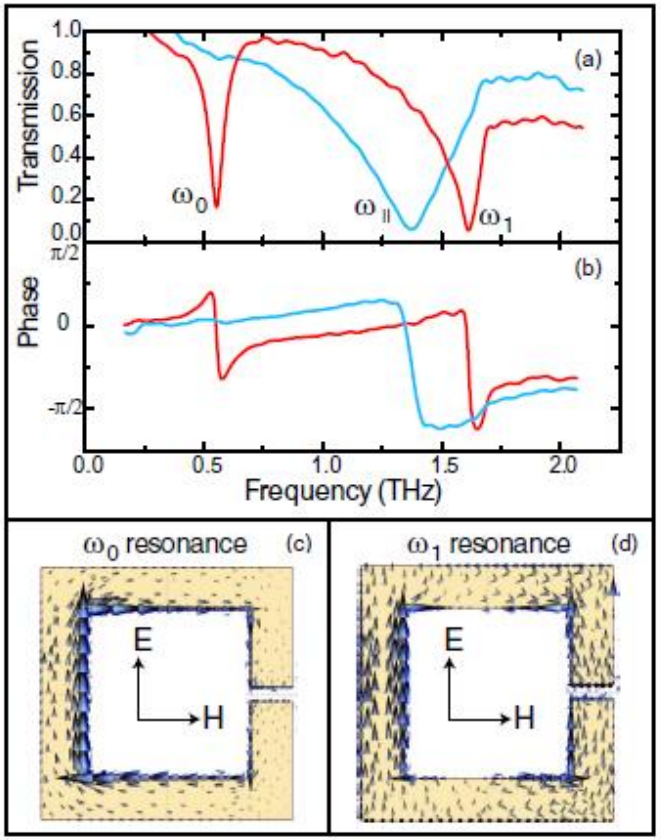
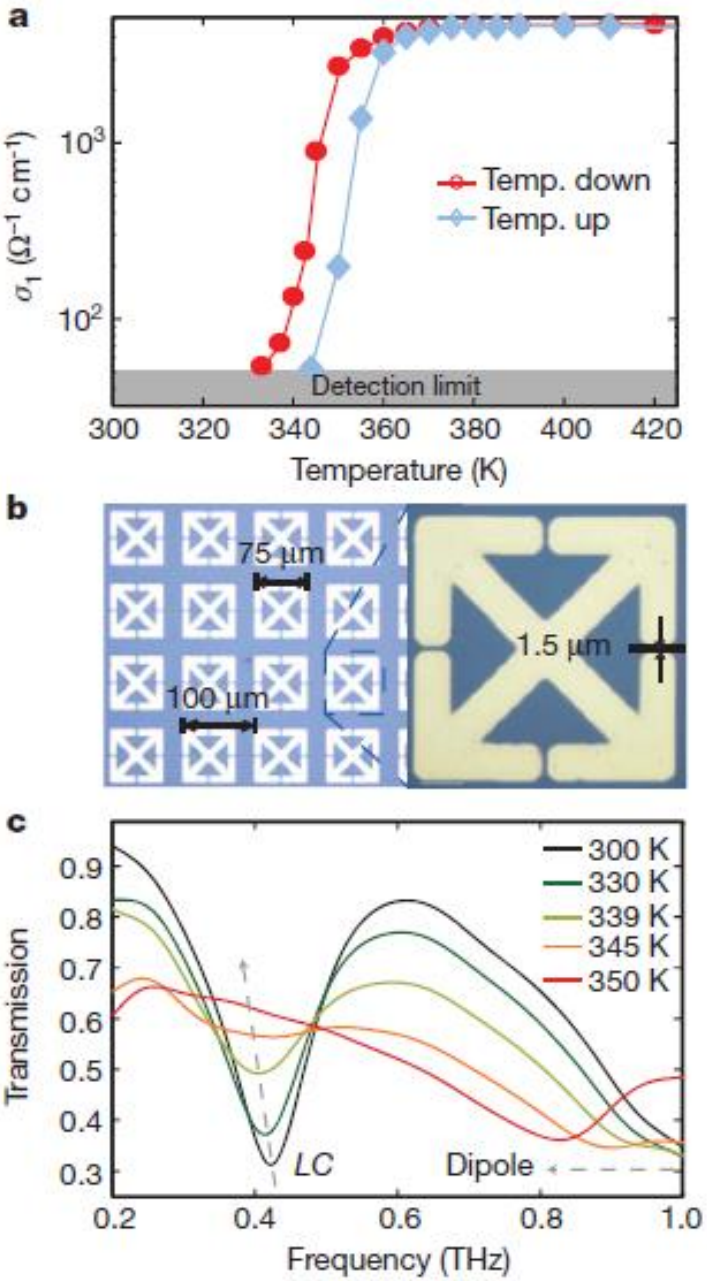


FIG. 1 (color online). The frequency dependent transmission spectra $T(\omega)$ of the SRR sample is shown in (a), and in (b) the corresponding phase of the transmission is shown. In (a) and (b), the electric field is perpendicular to the SRR gap [red (dark) curves] and parallel to the SRR gap [blue (light) curves] at normal incidence. (c) and (d) are the surface current densities for the ω_0 (0.5 THz) and ω_1 (1.6 THz) resonances, respectively, as calculated by simulation. See the text for details.

VO_2



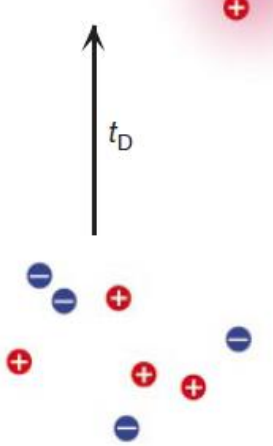
PRL **96, 107401 (2006)**

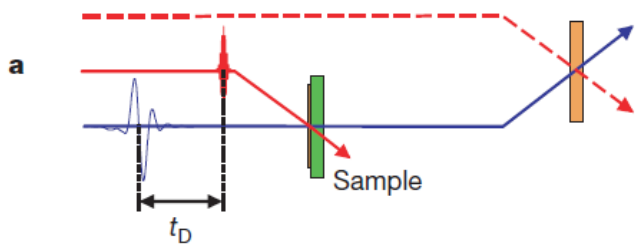
10.1038/nature11231

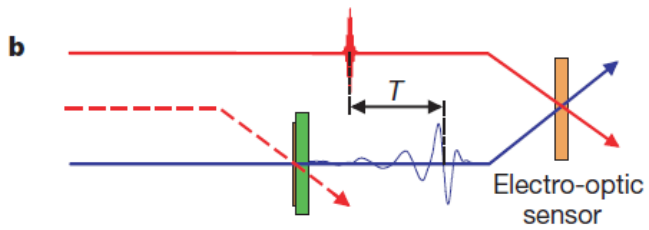
Coulomb gáz időfejlődése

$$W_q(\omega, t_D) = \frac{V_q}{\epsilon_q(\omega, t_D)}$$

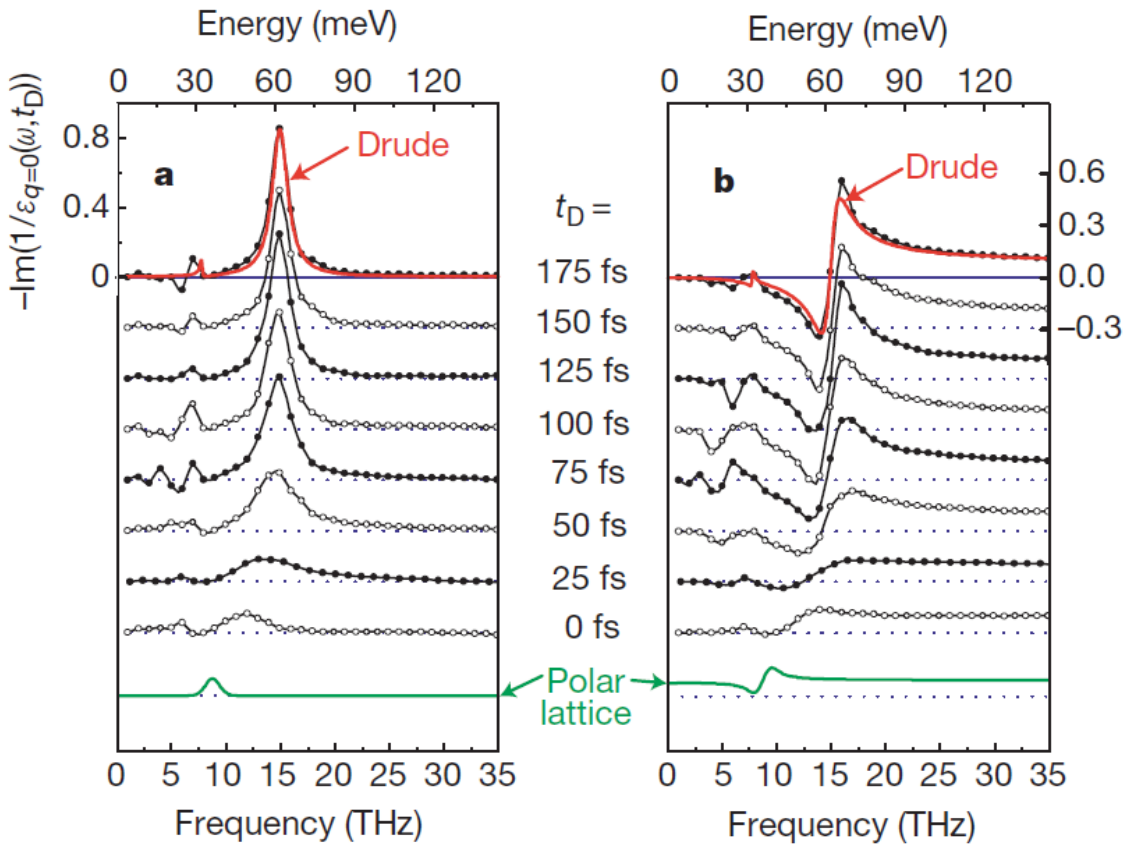
$$V_q = \frac{4\pi e^2}{q^2}$$





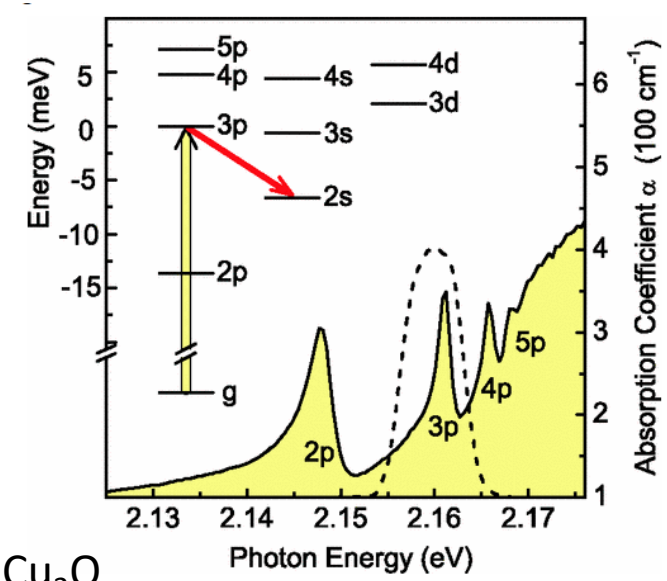


NIR pumpa – THz próba spektroszkópia

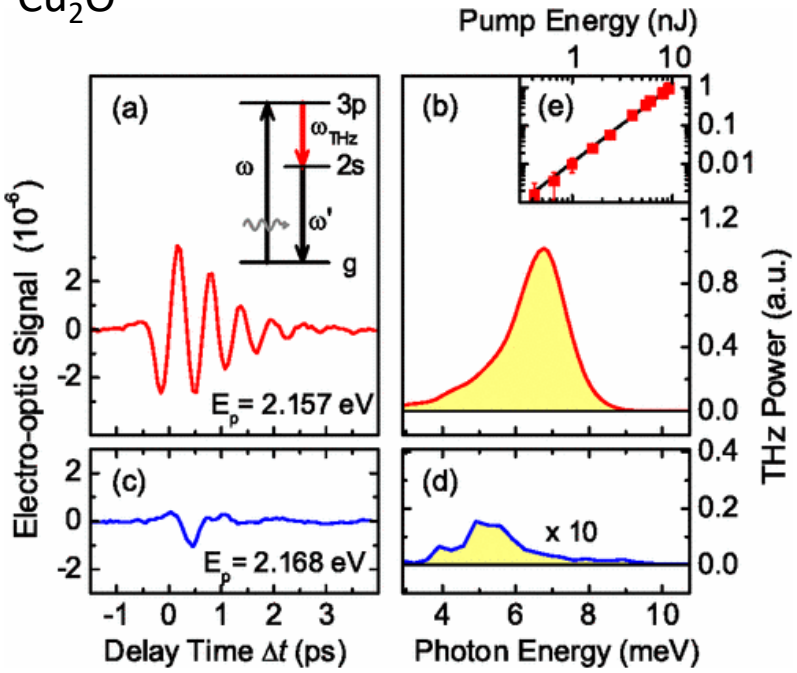


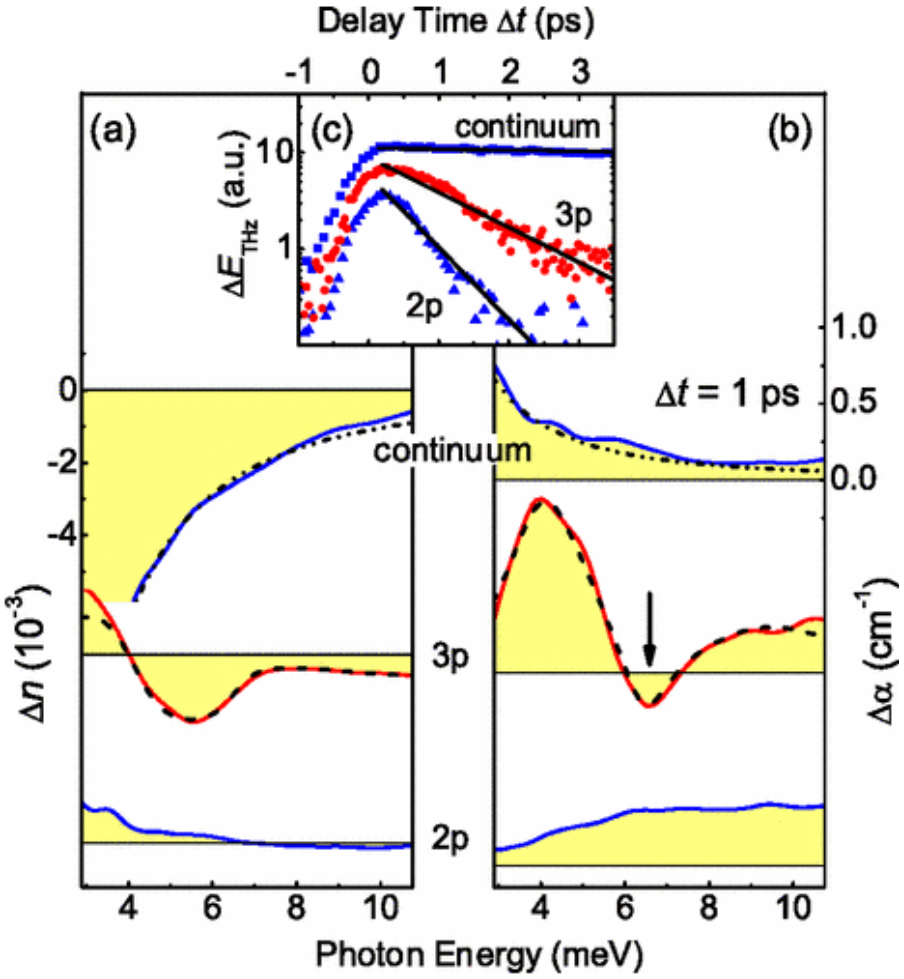
R. Huber et al., *Nature* **414** 286 (2001)

Wannier-Mott excitons: $E_B = \frac{\mu e^4}{2\hbar^2\varepsilon^2} = \frac{\hbar^2}{2\mu a_B^2}$ $\quad a_B = \frac{\hbar^2\varepsilon}{\mu e^2}$



Cu_2O





THz response at Δt=1 ps

Phys. Rev. Lett. **96**, 017402