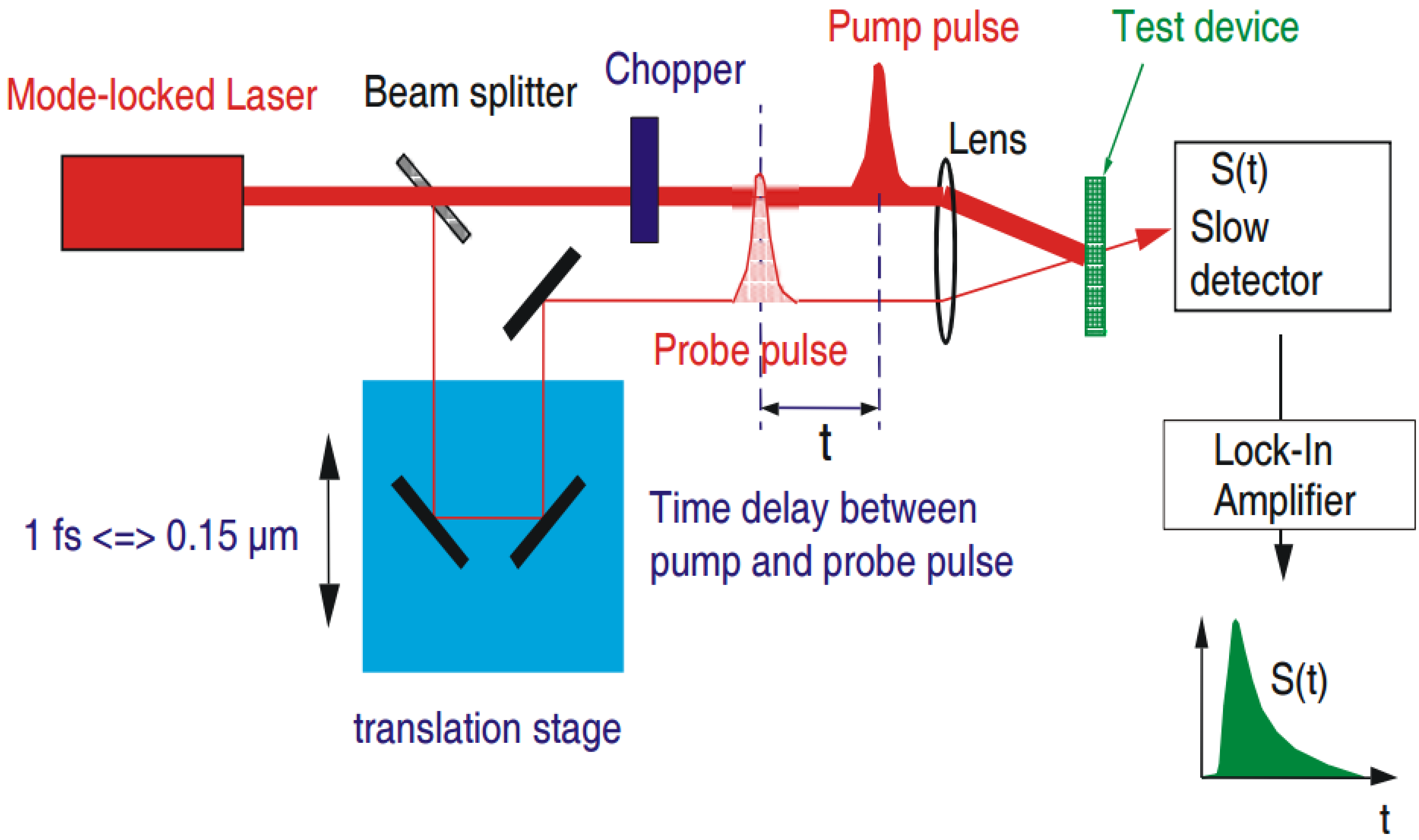
Time-resolved spectroscopy

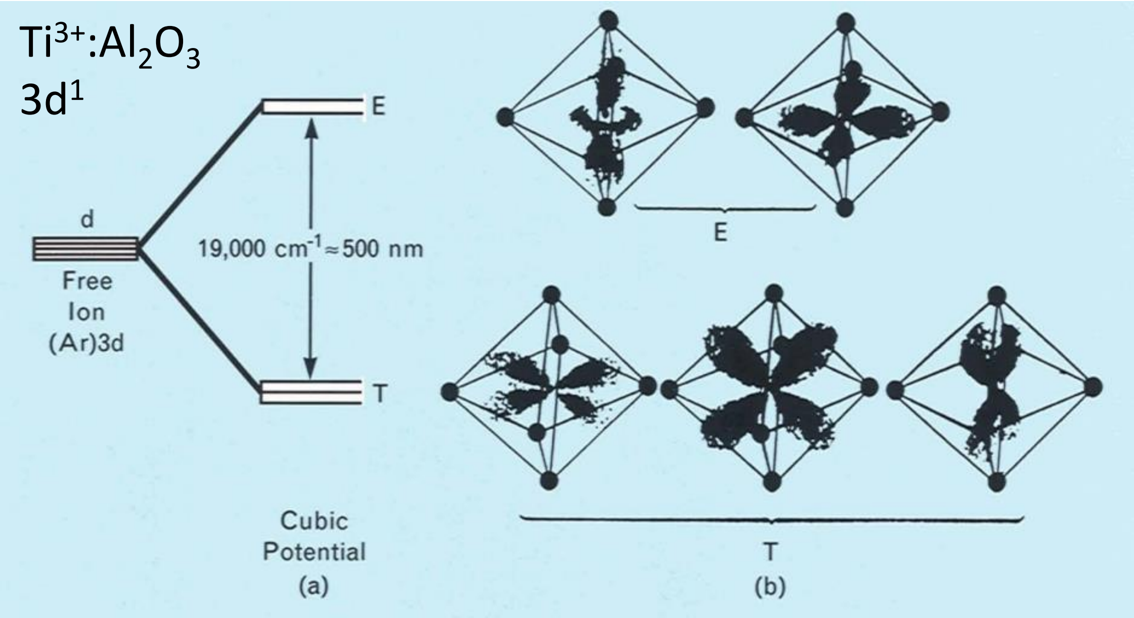
Time-resolved absorption/reflectivity/luminescence ...

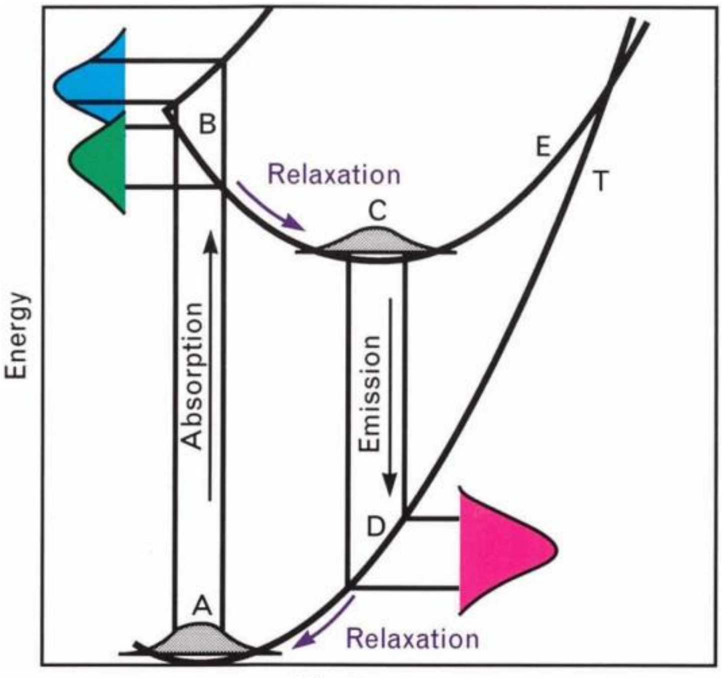


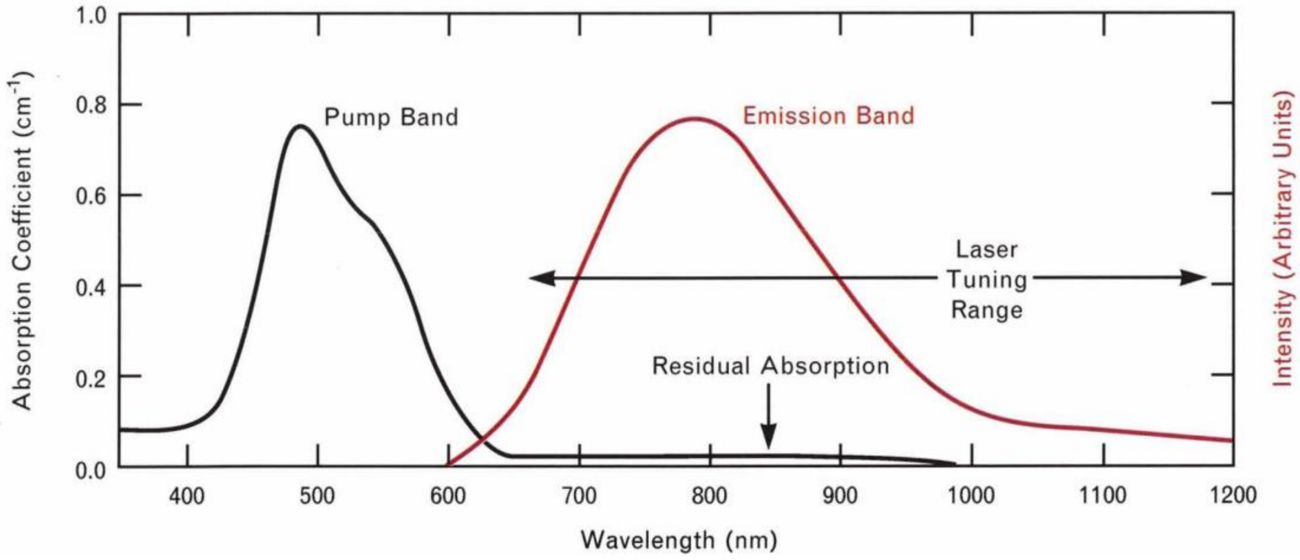
U. Keller ETH, Zürich

Ti:sapphire LASER

$Ti^{3+}:Al_2O_3$
$3d^1$

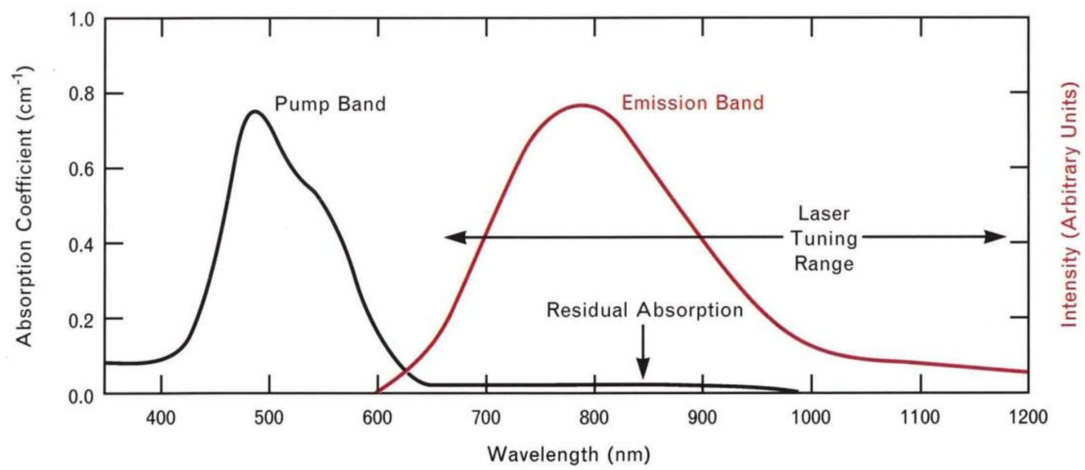




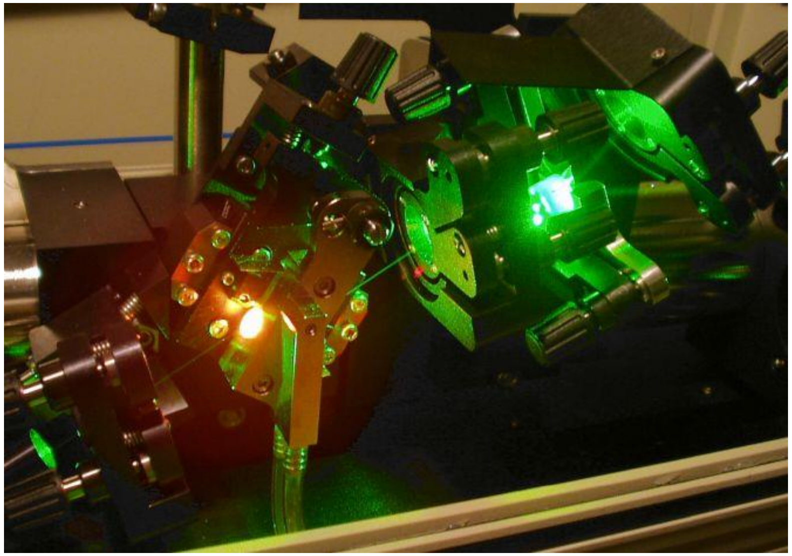


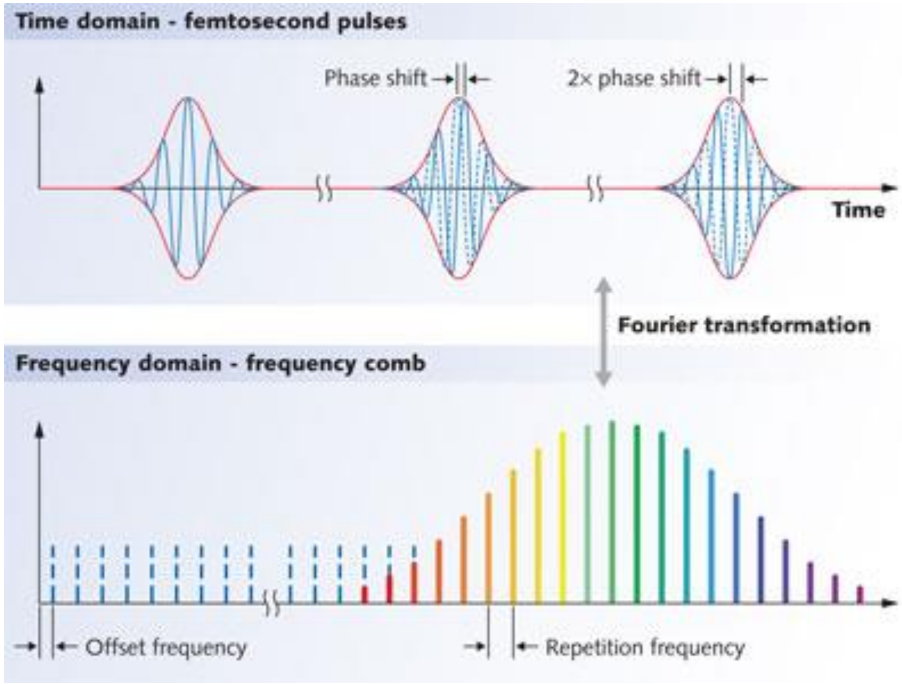
K.F. Wall and A. Sanchez. The Lincoln Laboratory Journal, 2 447 (1990)

Ti:sapphire LASER



Pump: green, lasing: NIR





Cental wavelength: 800 nm (375 THz)

Pulse width: 10-100 fs

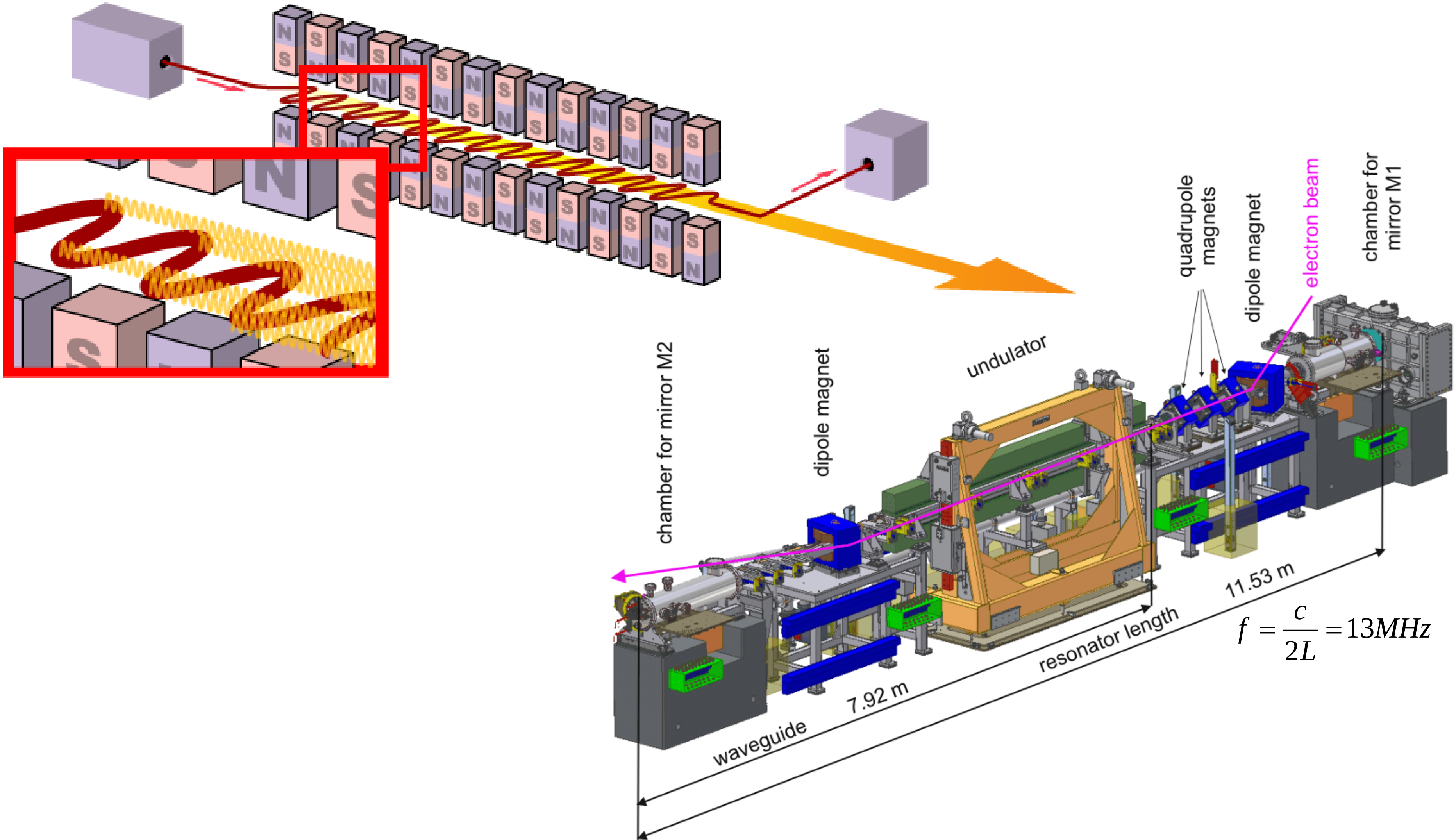
Repetition rate: 80 MHz ($\frac{c}{2L}$), resonantor: ~2 m

Free Electron LASER (FEL)

Lasing medium: relativistic free electrons traveling in an undulator

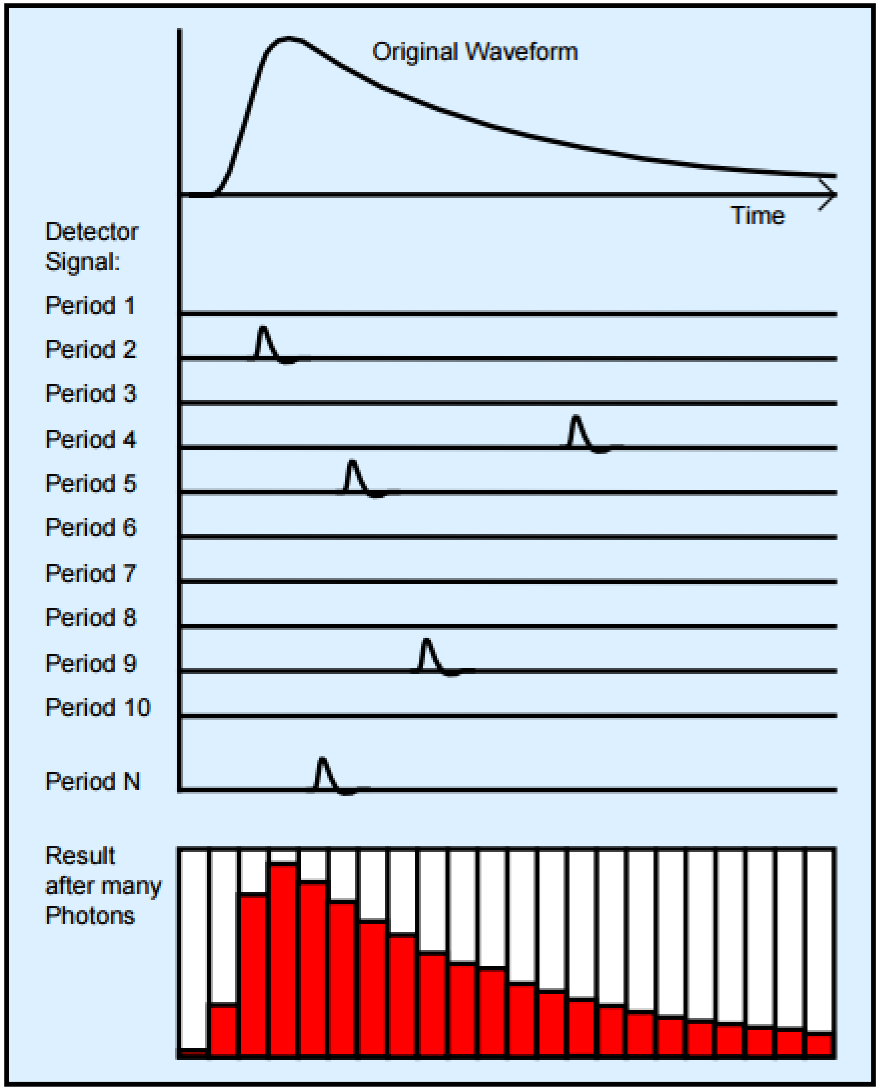
Interaction between the electron beam and the E-field of the radiation leads to bunching and coherent radiation

Most widely tuneable LASER: from microwave to X-ray

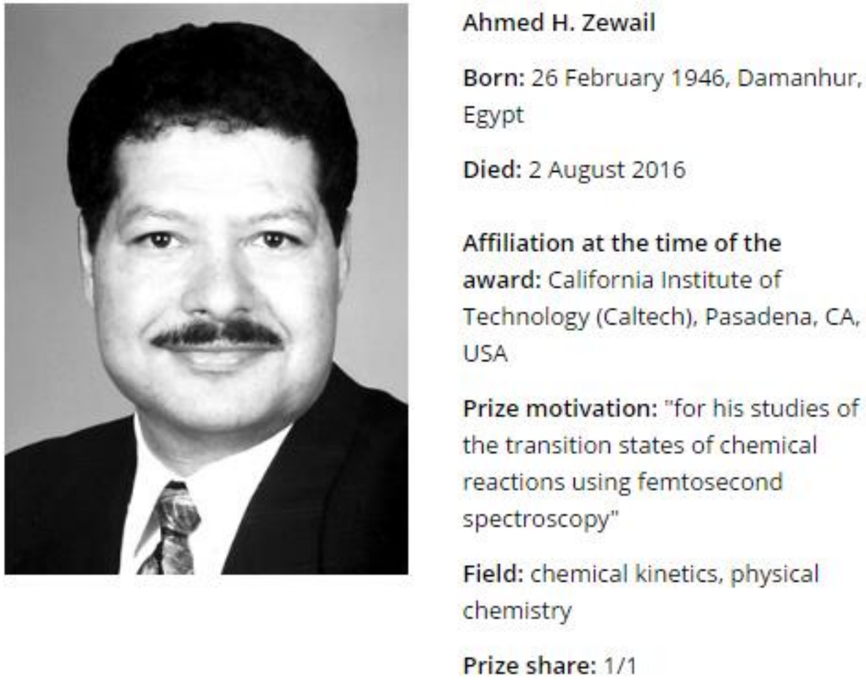


$$f = \frac{c}{2L} = 13MHz$$

Time-Correlated Single Photon Counting



Ahmed Zewail - Facts



Ahmed H. Zewail

Born: 26 February 1946, Damanhur, Egypt

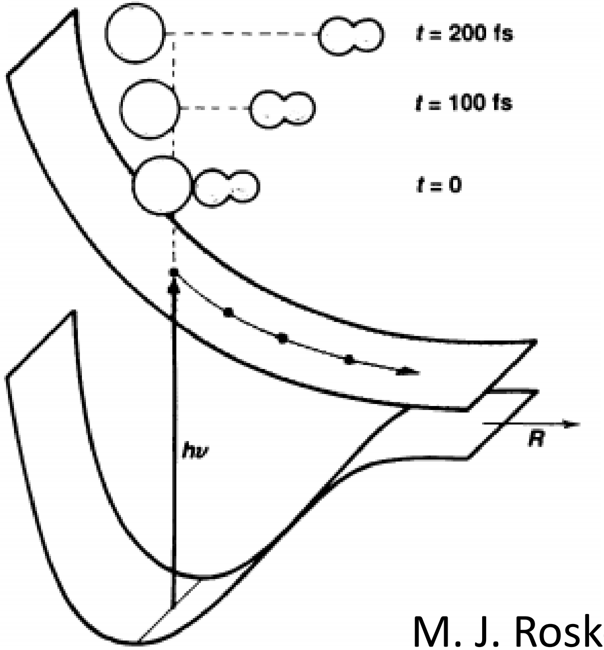
Died: 2 August 2016

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

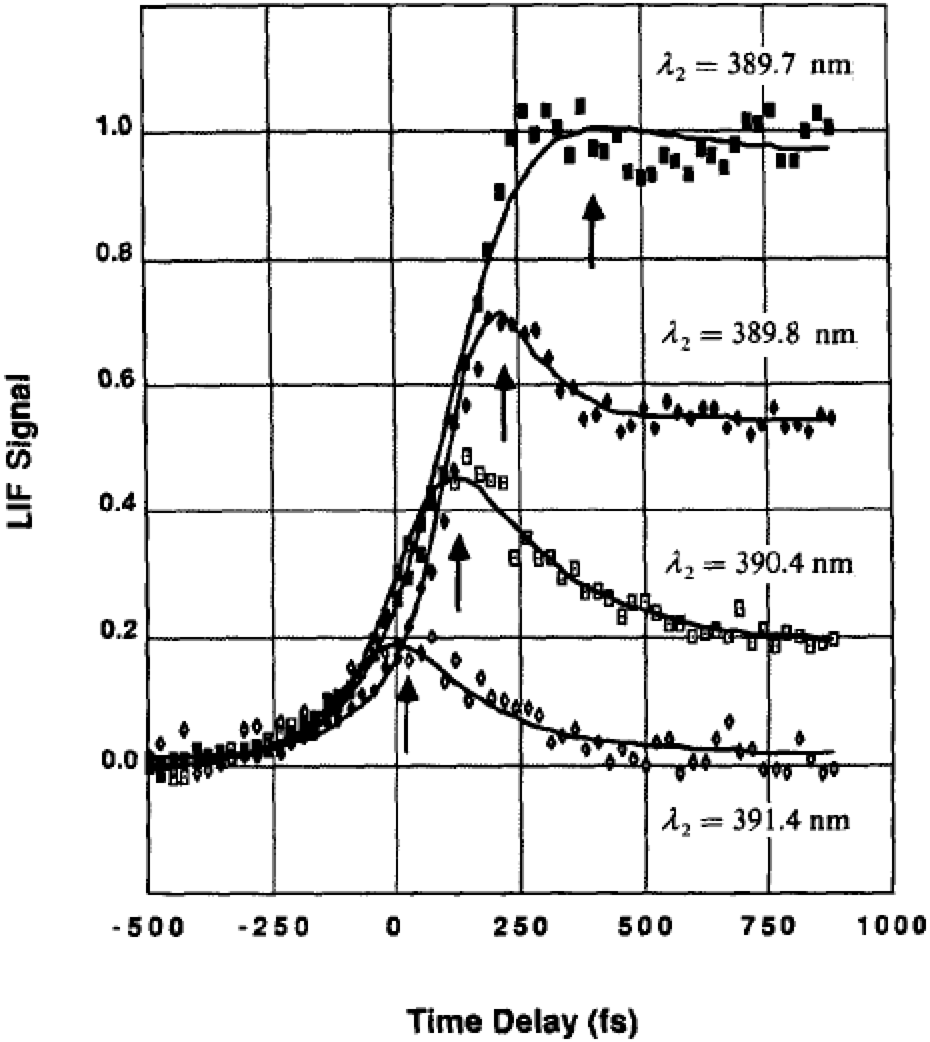
Prize share: 1/1



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

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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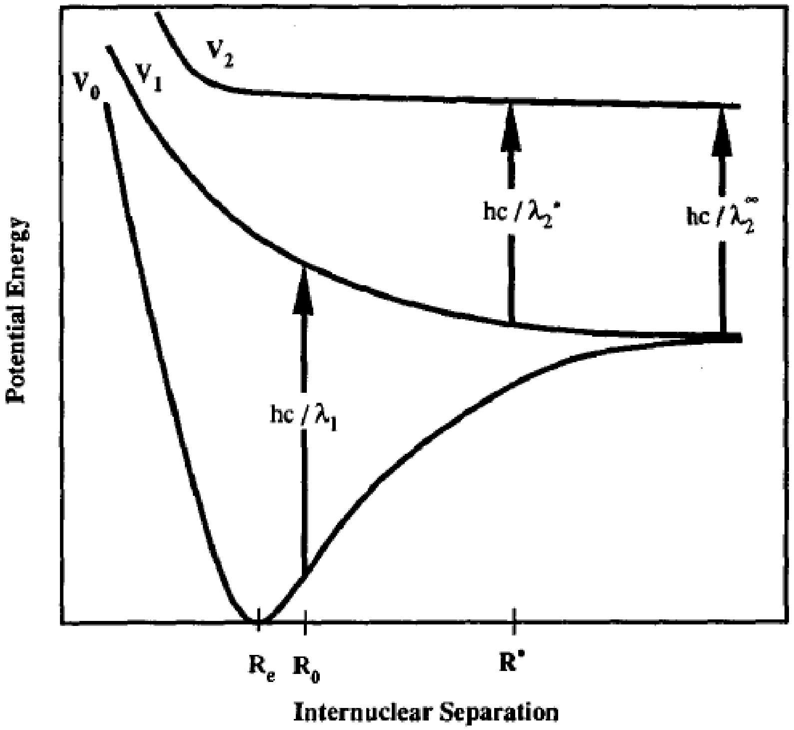
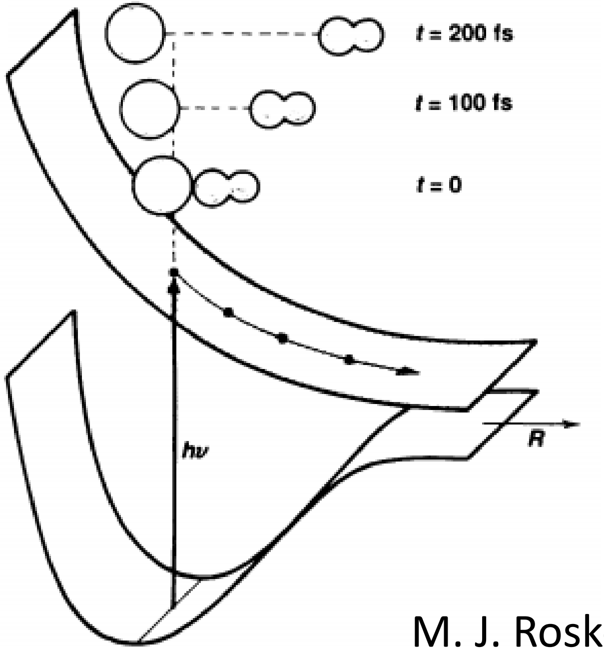
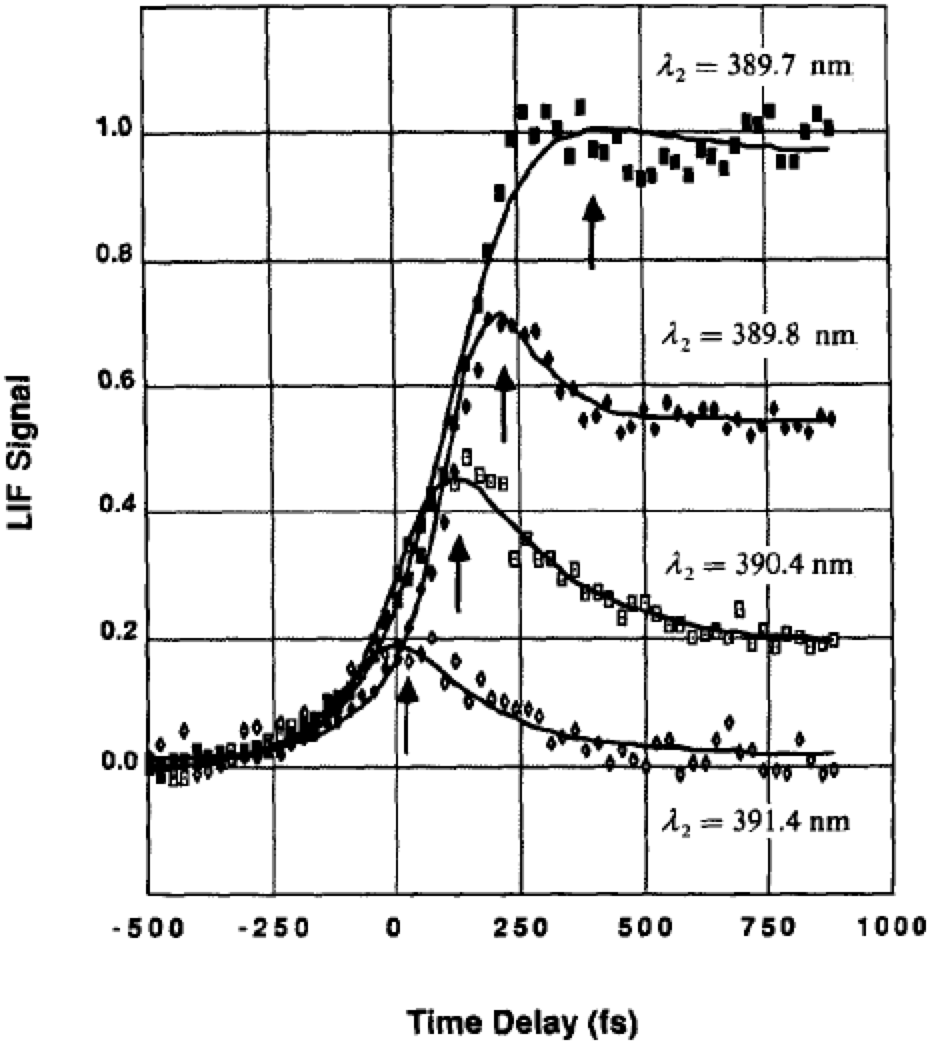
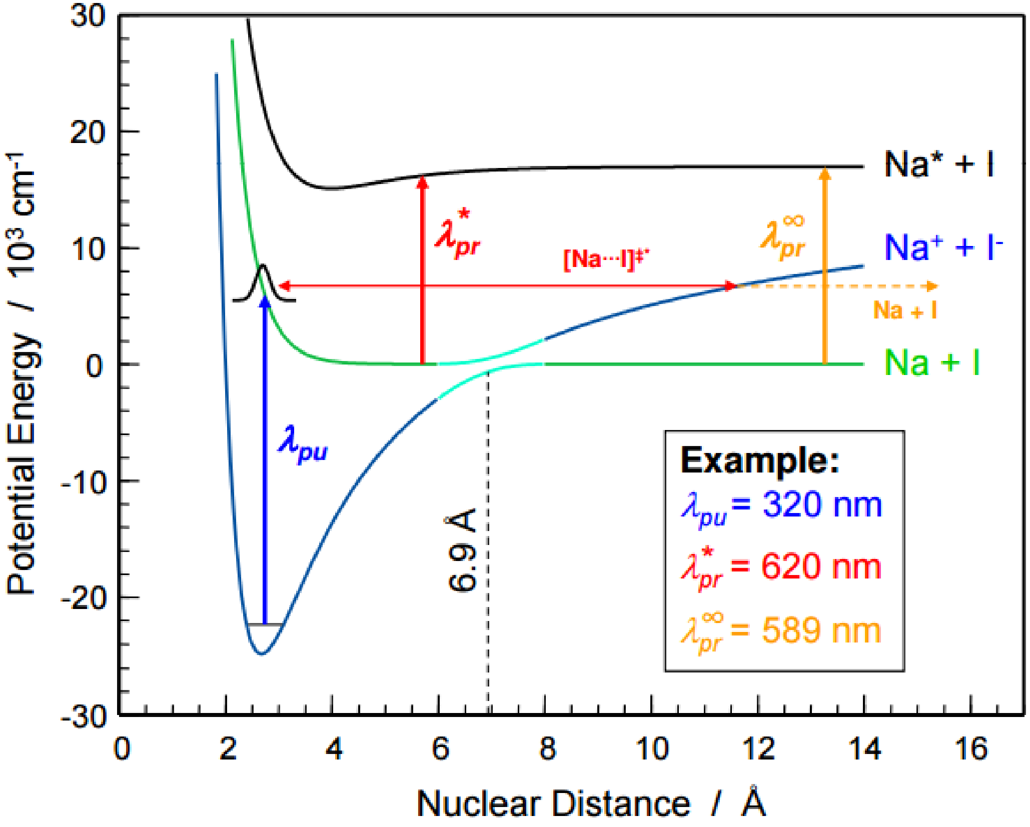
Fluorescence signal is measured after absorption

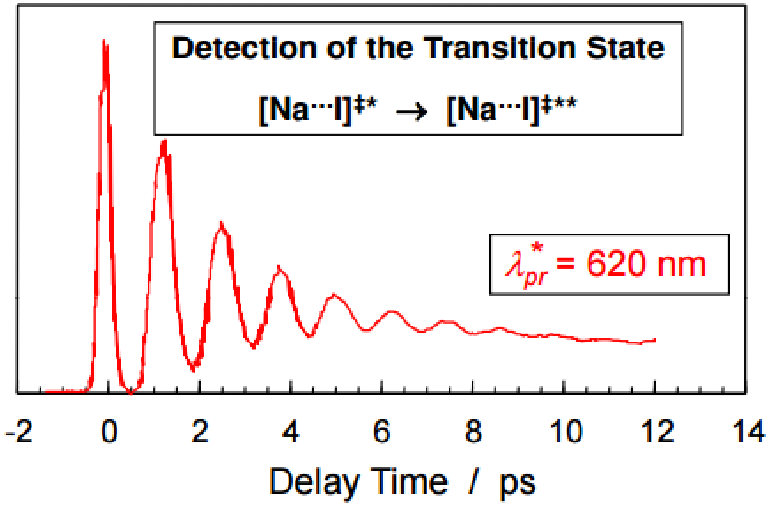


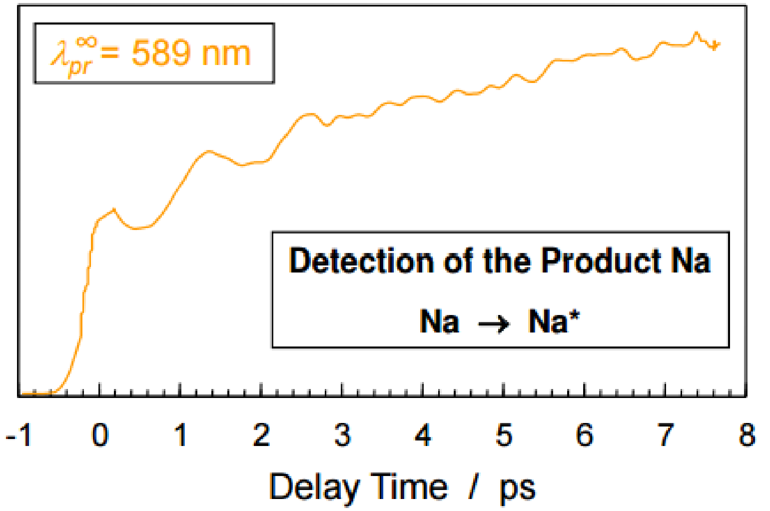




M. J. Rosker, M. Dantus, A. H. Zewail, J. Chem. Phys. **89**, 6113 (1988).

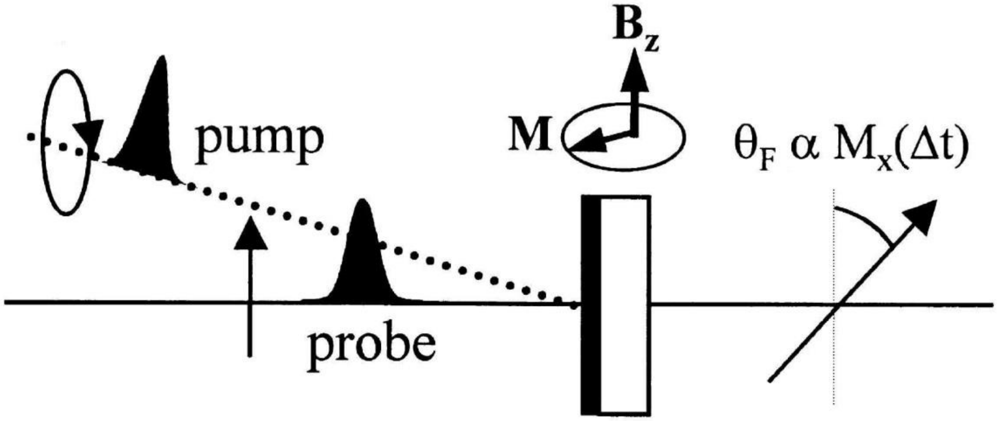




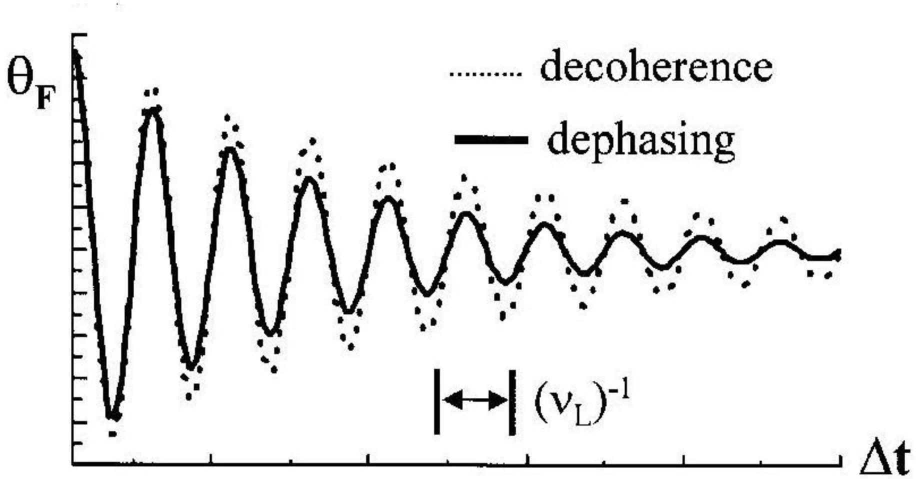


M. J. Rosker, M. Dantus, A. H. Zewail, J. Chem. Phys. **89**, 6113 (1988).
A. Materny, Jacobs University Bremen (2009).

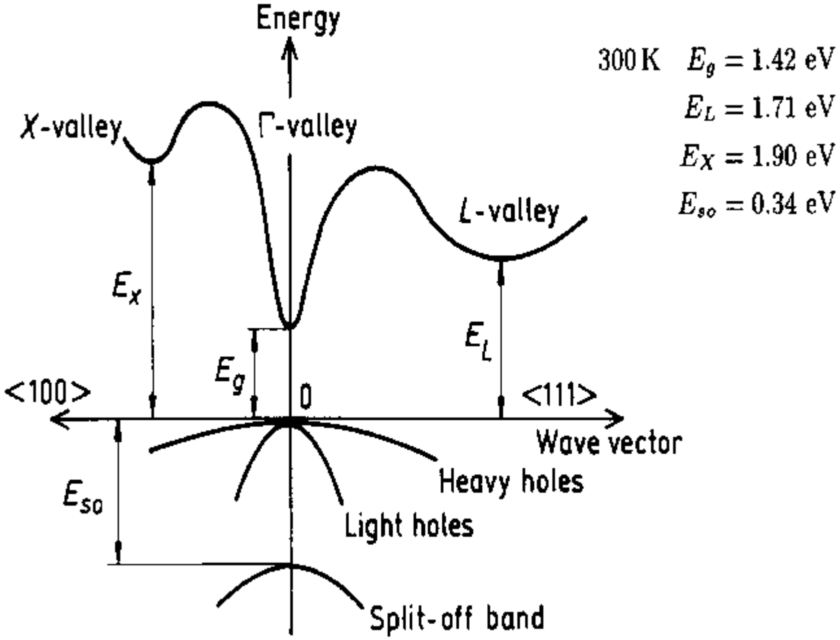
Time-domain magneto-optical spectroscopy



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



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



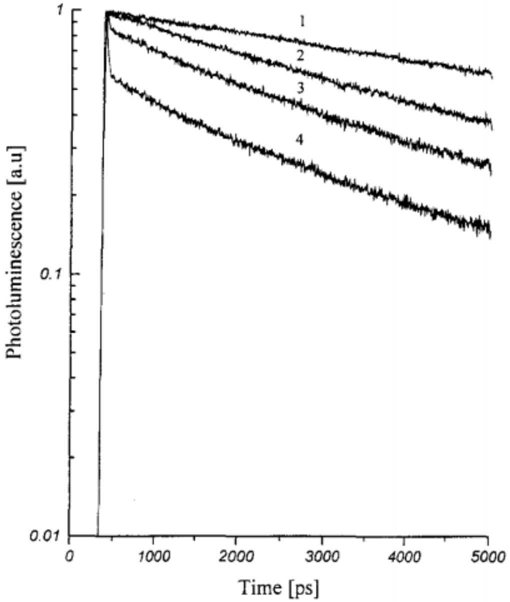
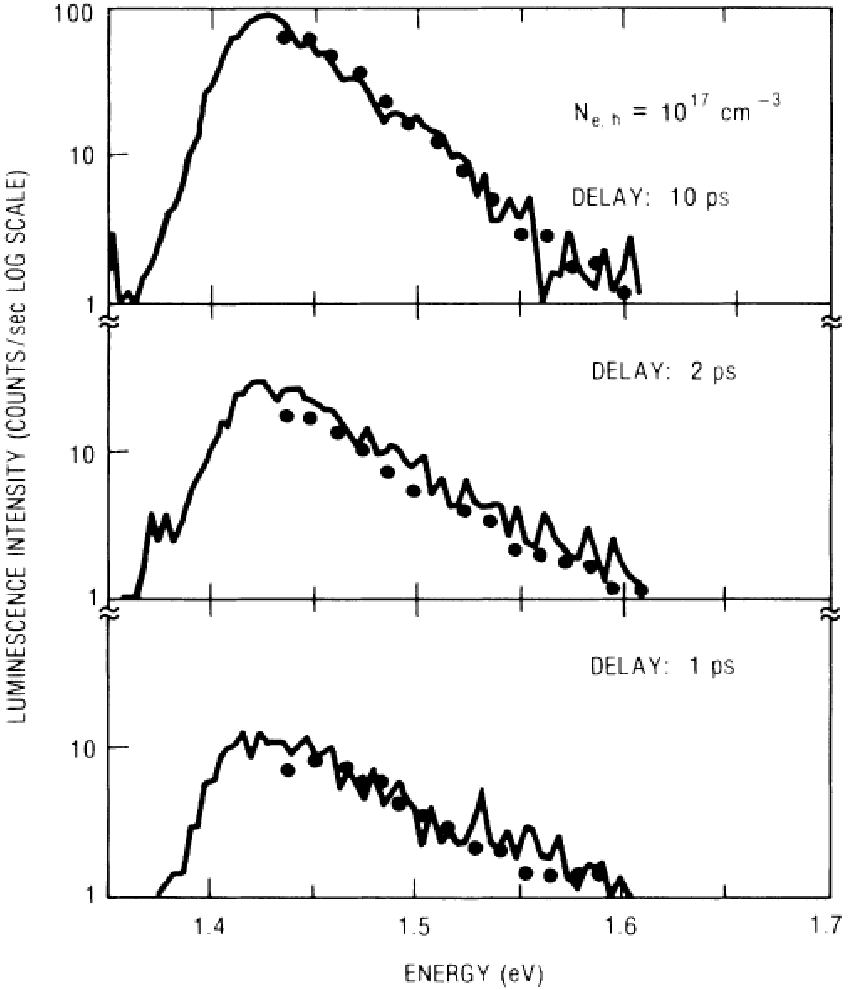


Fig. 1. Semilog plots of time resolved photoluminescence (PL) measured at various photon energies of 0.5 μm GaAs crystal. Curves 1, 2, 3 and 4 correspond to PL energy of: 1.43 eV, 1.49 eV, 1.57 eV, 1.65 eV, respectively.

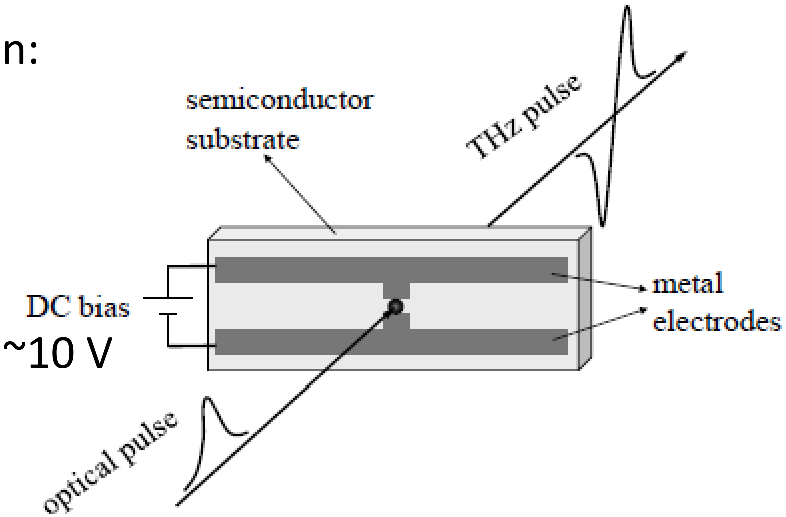


Applied Surface Science 106 (1996) 457-465

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

Terahertz sugárzás keltése

Dipól antenna LT-GaAs-en:



~10 V

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

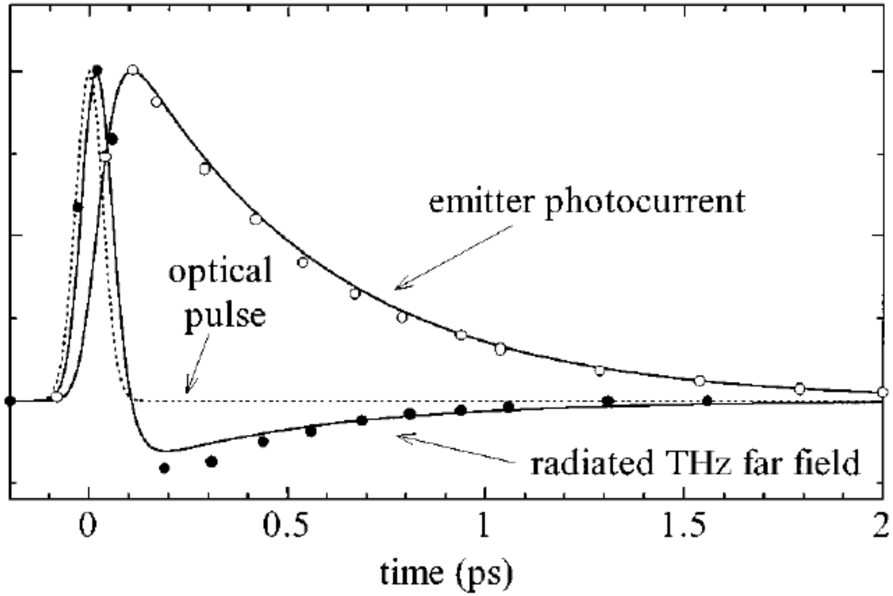
Ti:Sapphire LASER:
-központi hullámhossz: λ=800 nm
-impulzus szélesség: τ<100 fs

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

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

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

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



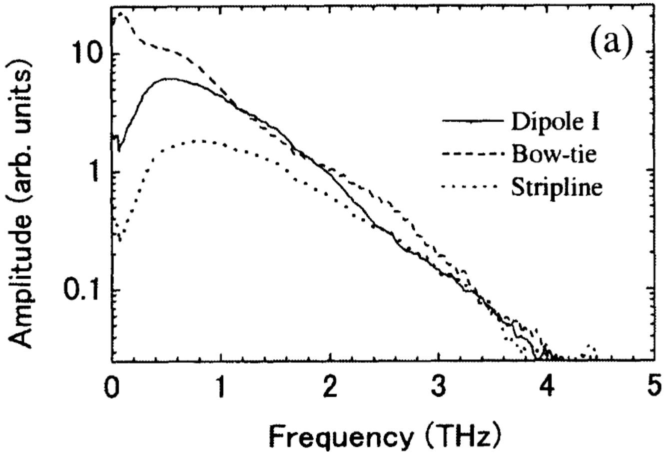
Y. S. Lee: Principles of Terahertz Science and Technology Springer, Berlin (2009)
L. Duvillaret et al. *IEEE J. Sel. Top. Quant. Electronics.* **7** 615 (2001)

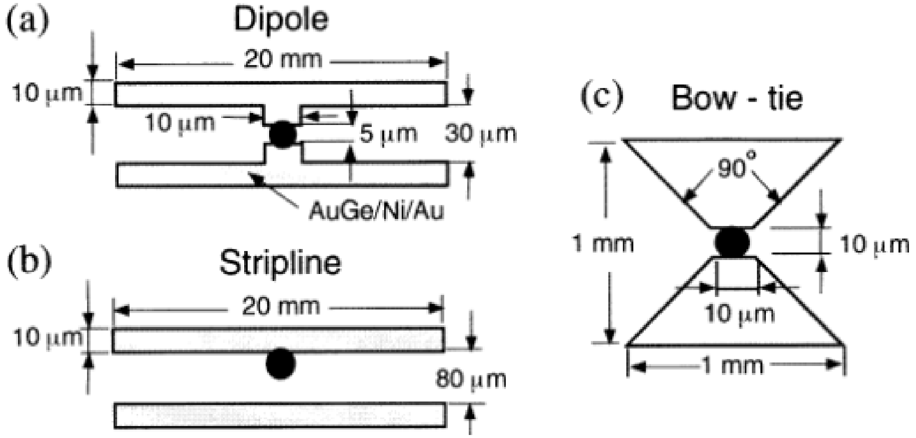
Terahertz sugárzás keltése

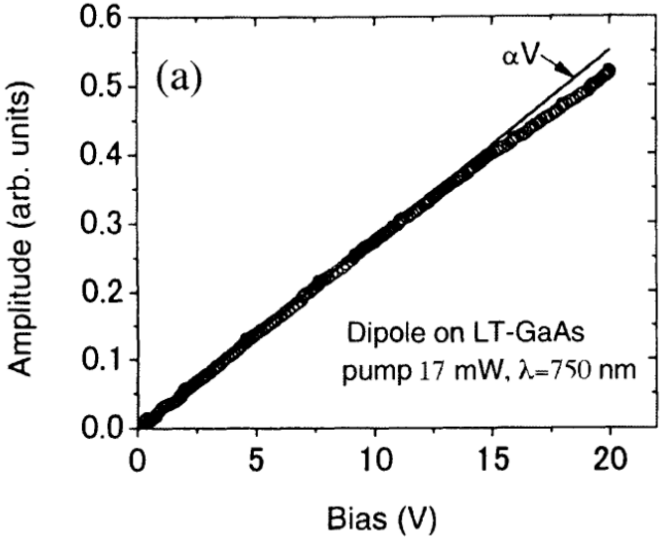
Ti:Sapphire
@ 800nm
20 mW

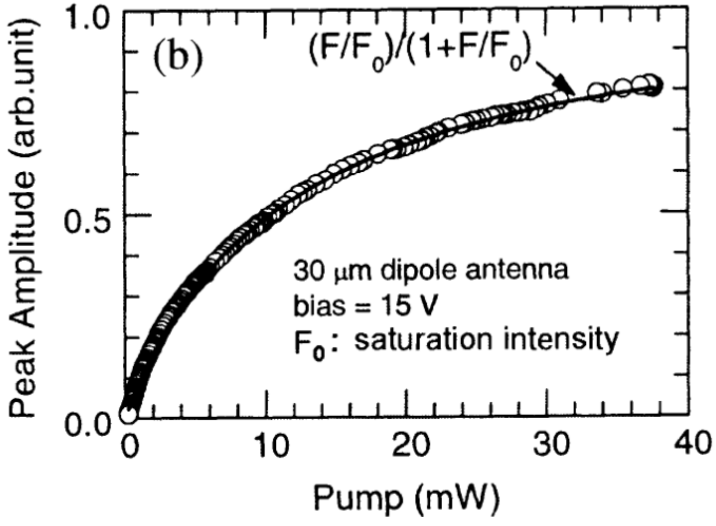
$\xrightarrow{60\ \mathrm{V}}$

THz sugárzás
2-3 µW





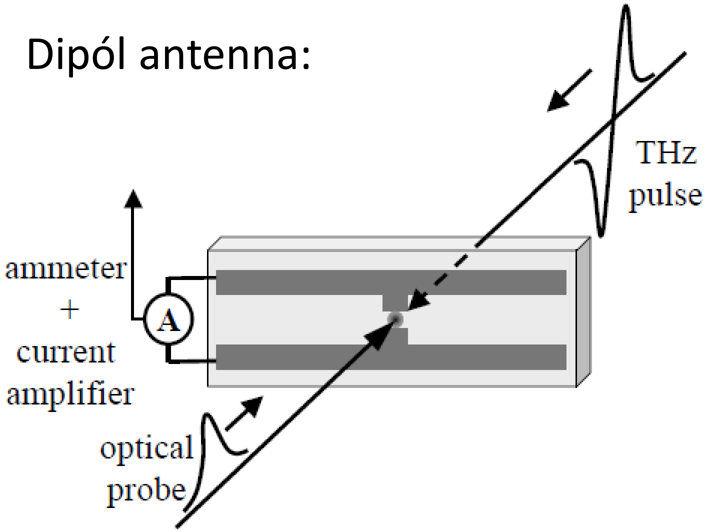




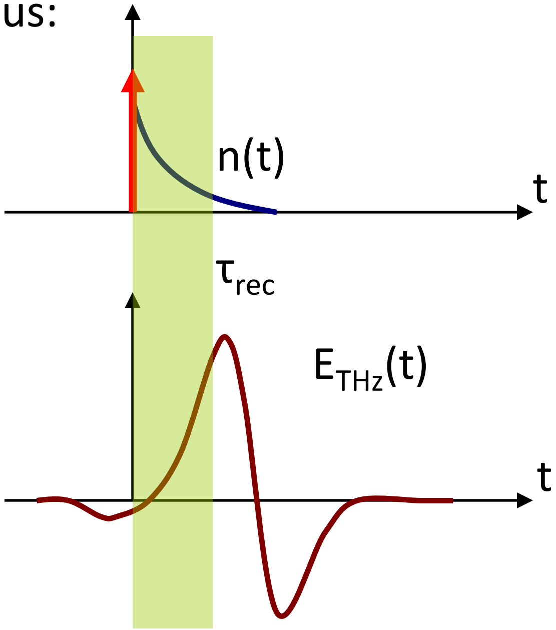
K. Sakai: Terahertz Optoelectronics Springer, Berlin (2005)

Terahertz sugárzás koherens detektálása

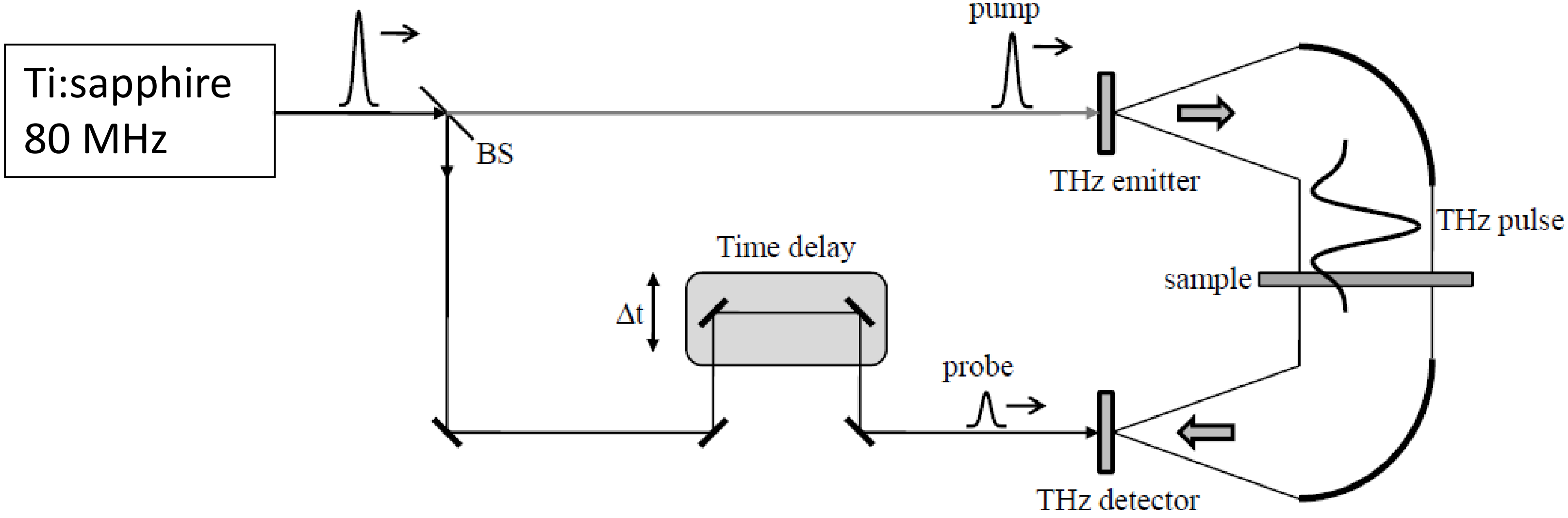
Dipól antenna:



δ-impulzus:



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



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

Terahertz sugárzás koherens detektálása

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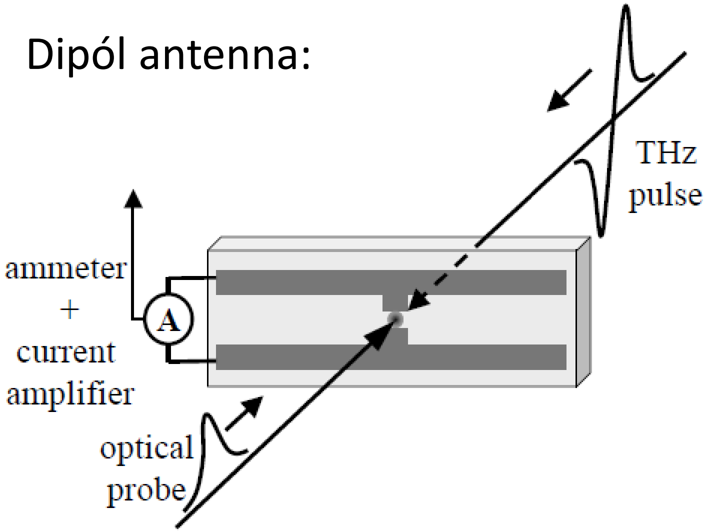
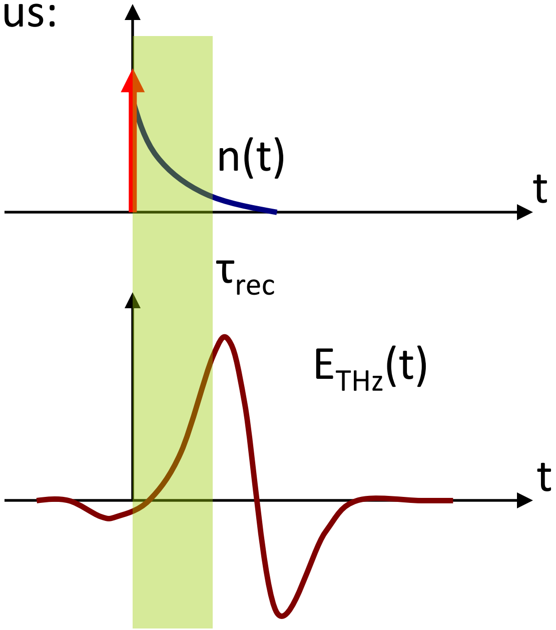


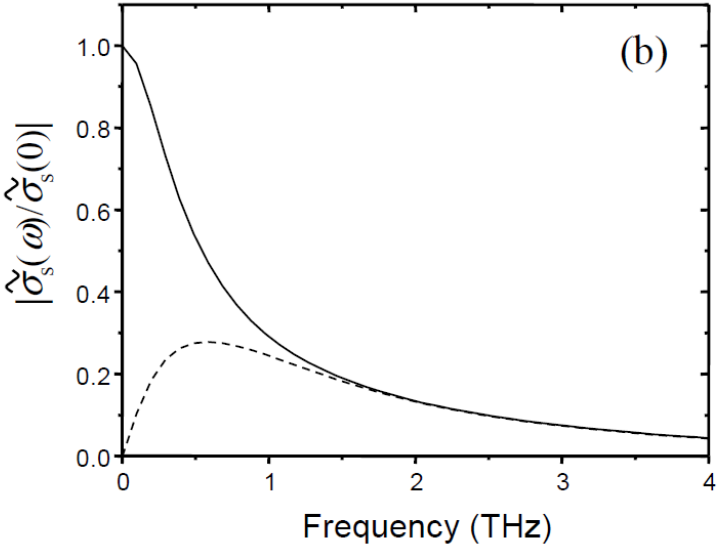
δ-impulzus:



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

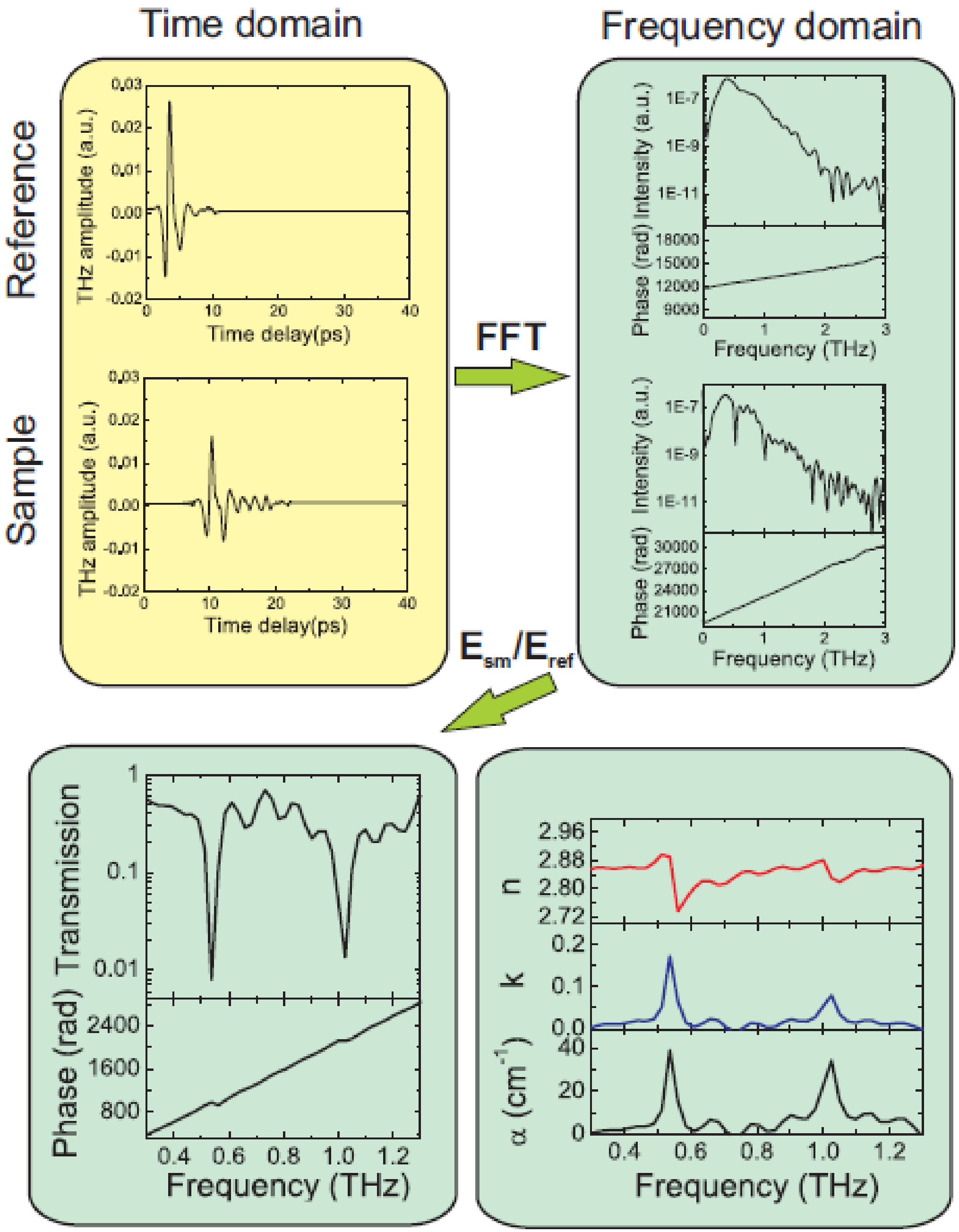
Nagy frekvenciás korlát: $1/\tau_{rec}$~3 THz

Alacsony frekvenciás limit: diffrakció limitált leképezés



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

Komplex THz spektrum

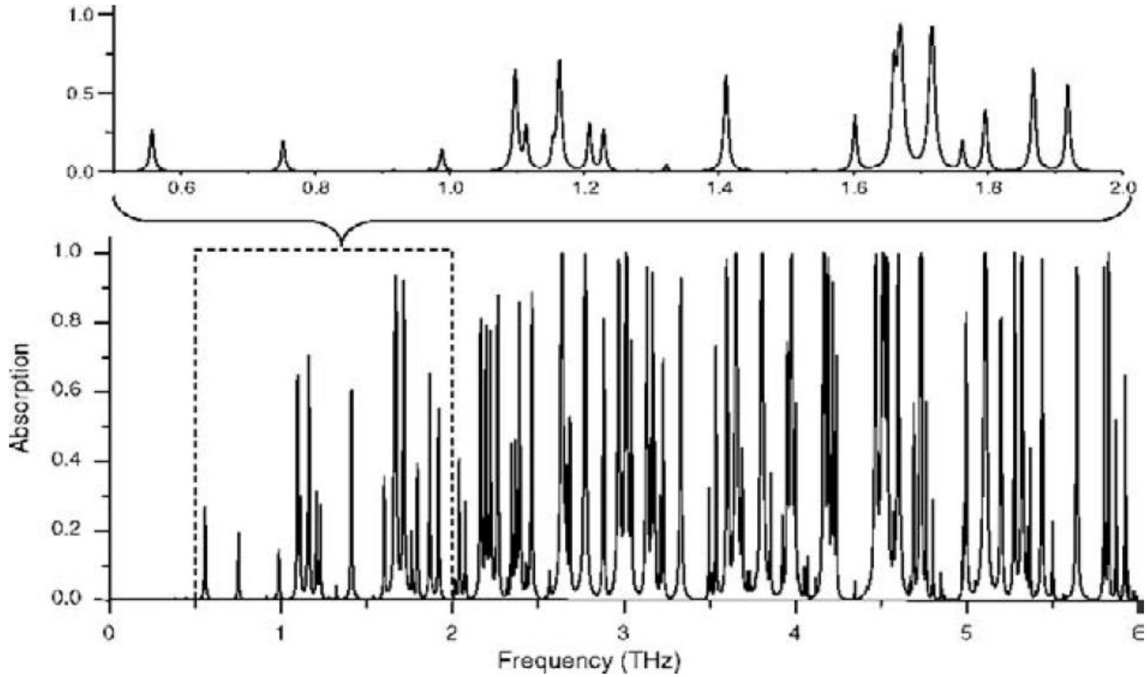


Molekulák ujjlenyomatai: rotációs spektrum

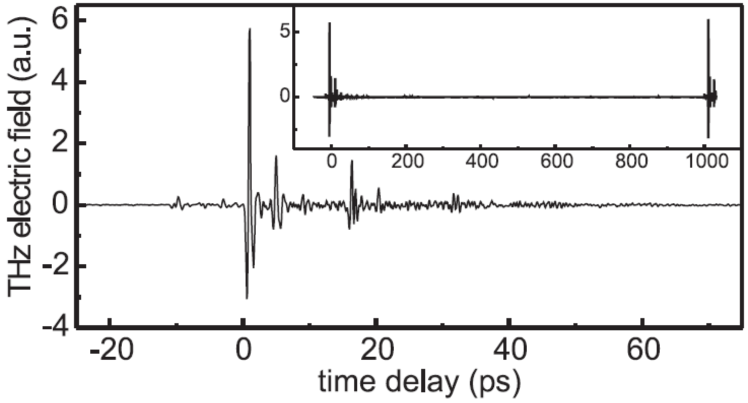
Molekulák forgási energiája:

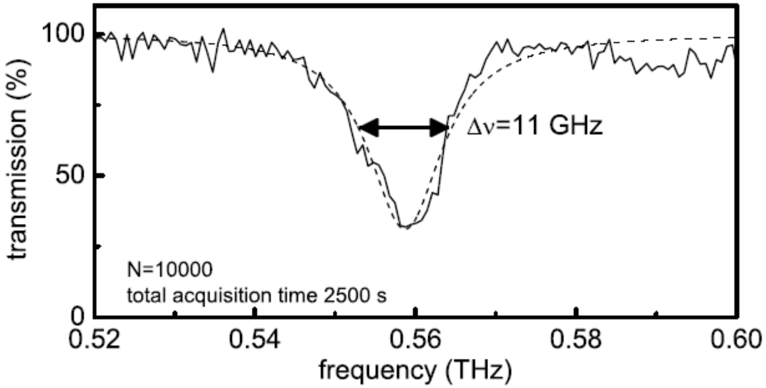
$$E \sim \frac{\hbar^2}{2MR^2} \sim 1THz$$

Víz gőz rotációs spektruma



Nagyfelbontású (~1GHz)
THz spektroszkópia:

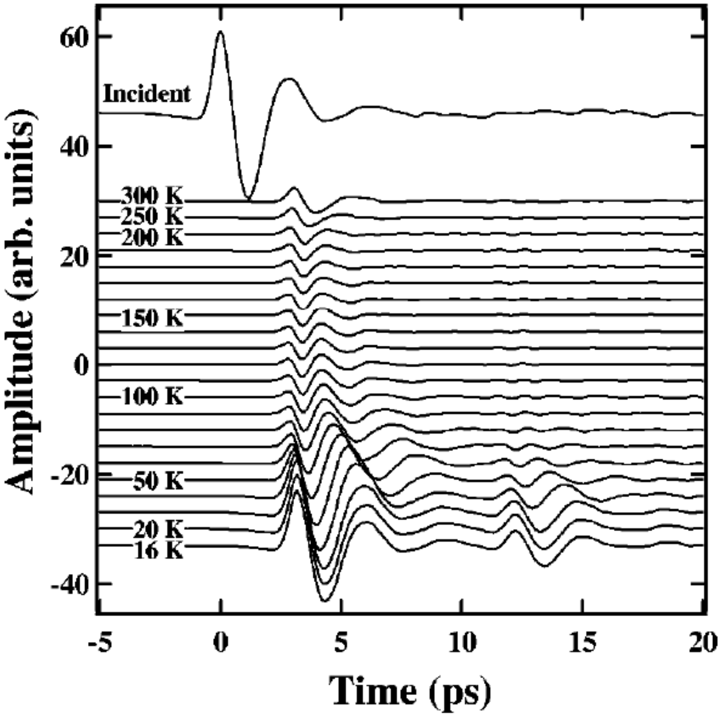


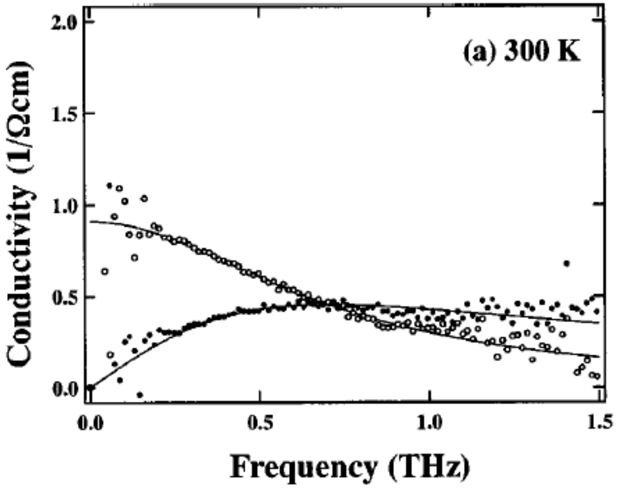


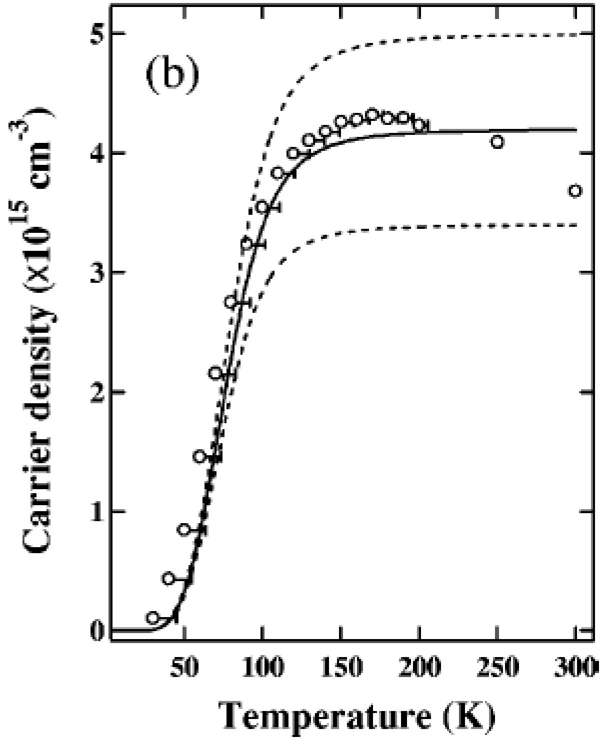
Y. S. Lee: Principles of Terahertz Science and Technology Springer, Berlin (2009)
A. Bartels et al., *Opt Exp* **14** 430 (2006)

Félvezető szeletek érintésmentes minősítése

Adalékolt p-Si szelet







$N_D = 4.2 \times 10^{15} \text{cm}^{-3}$

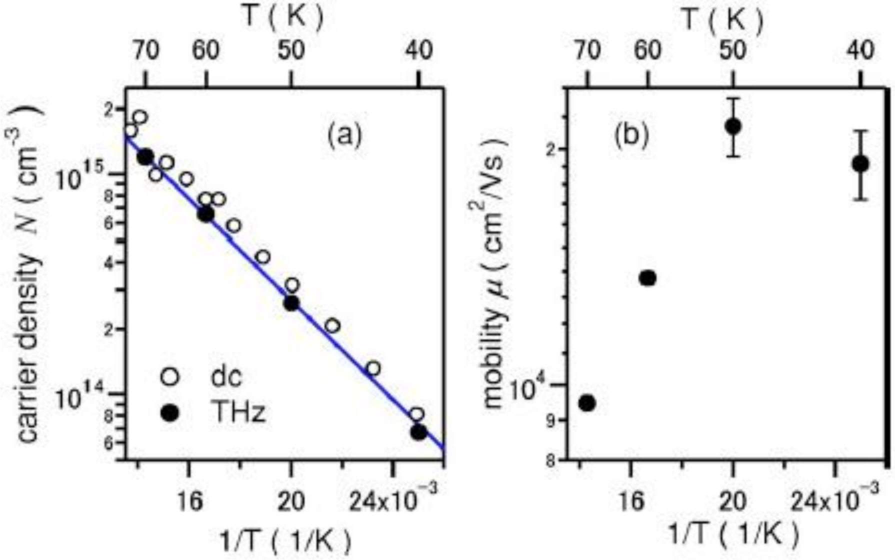
S. Nashima et al. *J. Appl. Phys.* **90** 15 (2001)

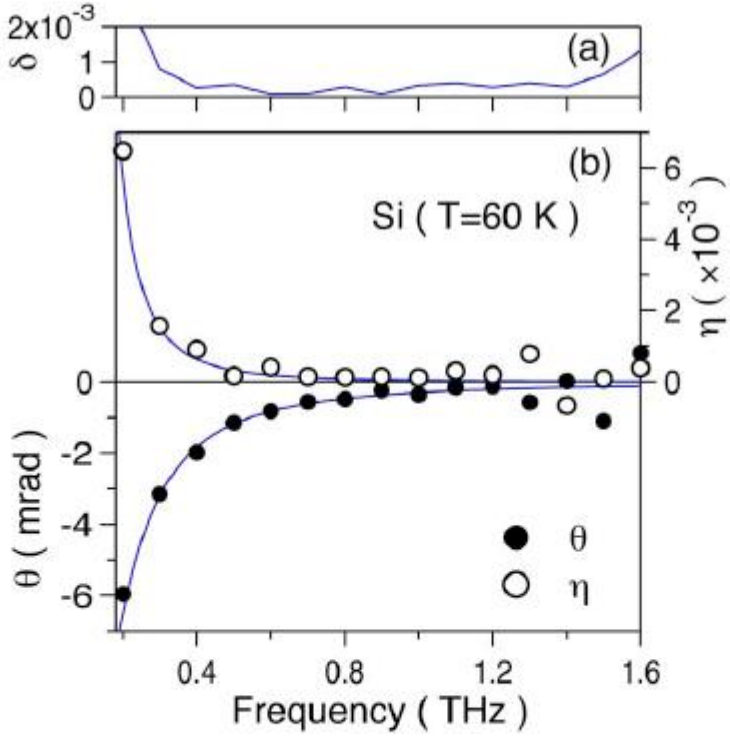
Félvezető szeletek érintésmentes minősítése

Adalékolt n-Si szelet

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

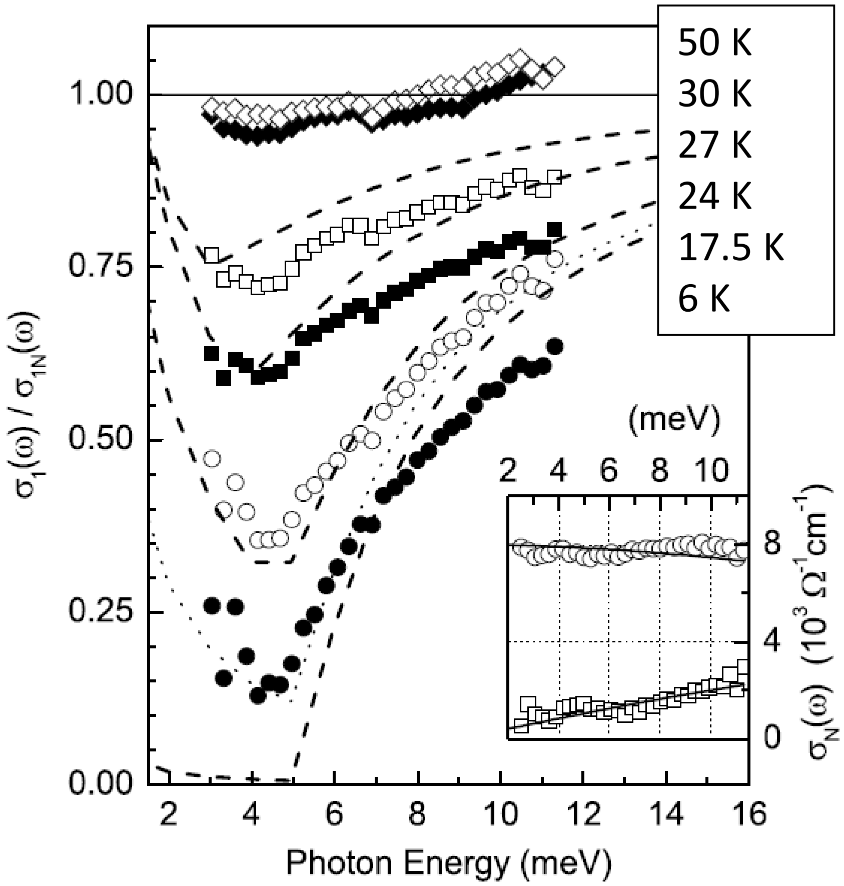
$$\theta + i\eta = -\frac{\omega}{2c}\frac{i\epsilon_{xy}}{\sqrt{\epsilon_{xx}}}d$$

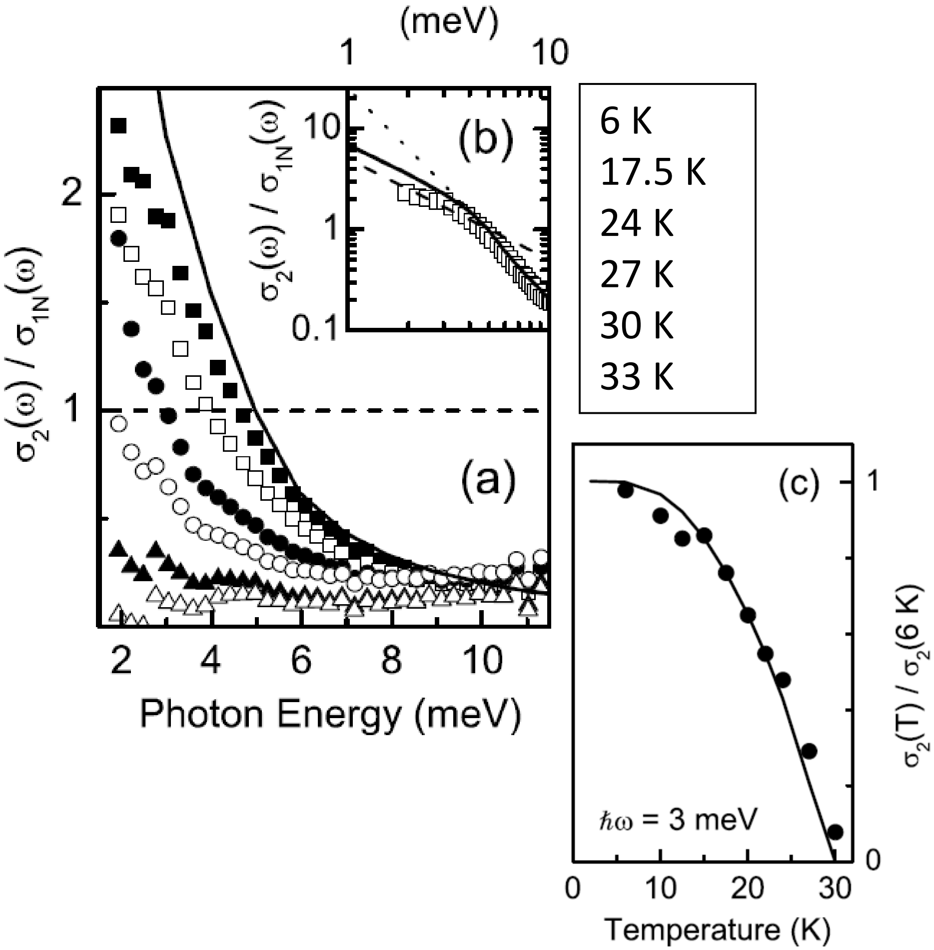




Appl. Phys. Lett. **92, 012111 2008**

Szupravezetők elektrodinamikája: MgB_2





BCS fit: $2\Delta_o$=5 meV

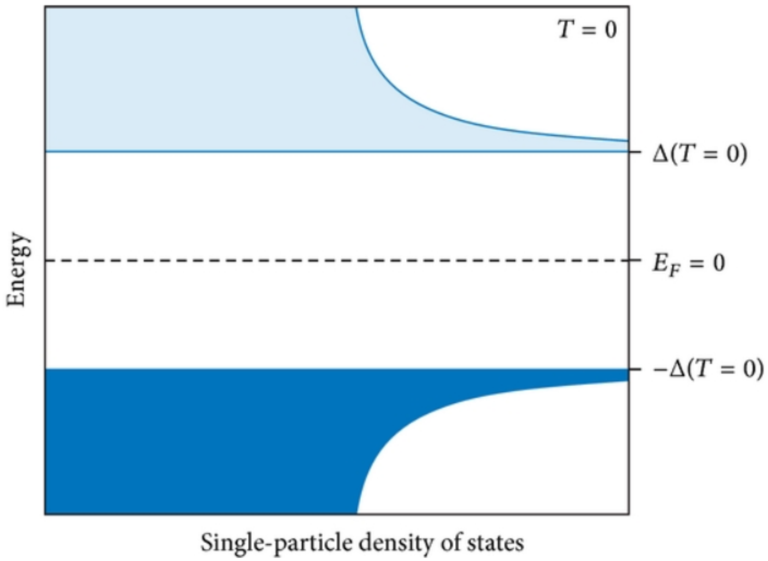
Gyenge csatolás: $2\Delta_o=3.5k_BT_C$=9 meV

Gap alatt kvázirészecske gerjesztés

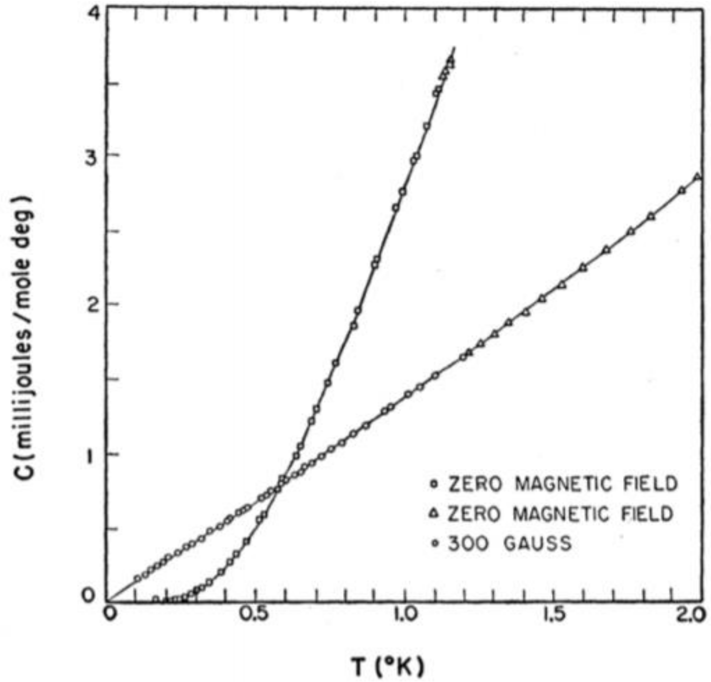
R. A. Kaindl et al., *Phys. Rev. Lett.* **88** 027003 (2002)

Correlated systems: superconductivity

BCS theory:



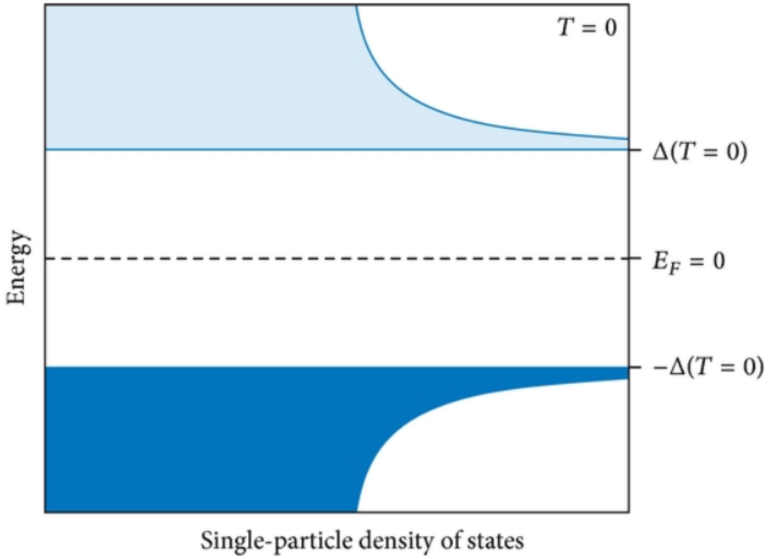
Norman E. Phillips. Heat Capacity of Aluminum between 0.1 K and 4.0 K. *Phys. Rev.*, 114(3):676–685, May 1959.

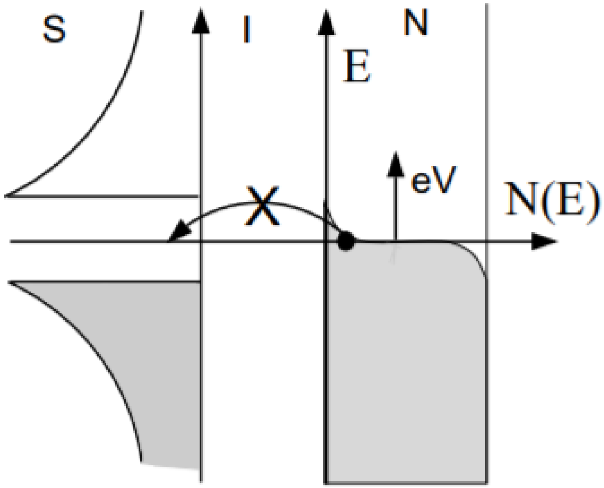


M. Dressel, Advances in Condensed Matter Physics 2013, 104379

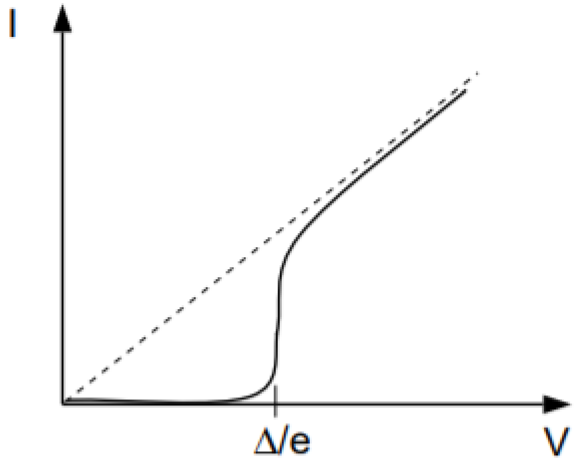
Superconductivity

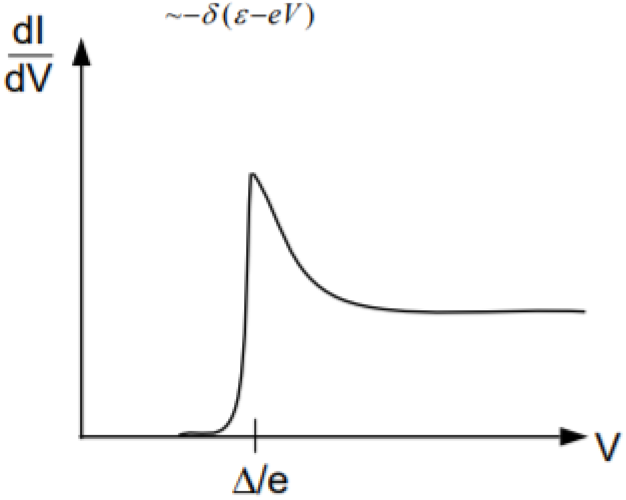
BCS theory:





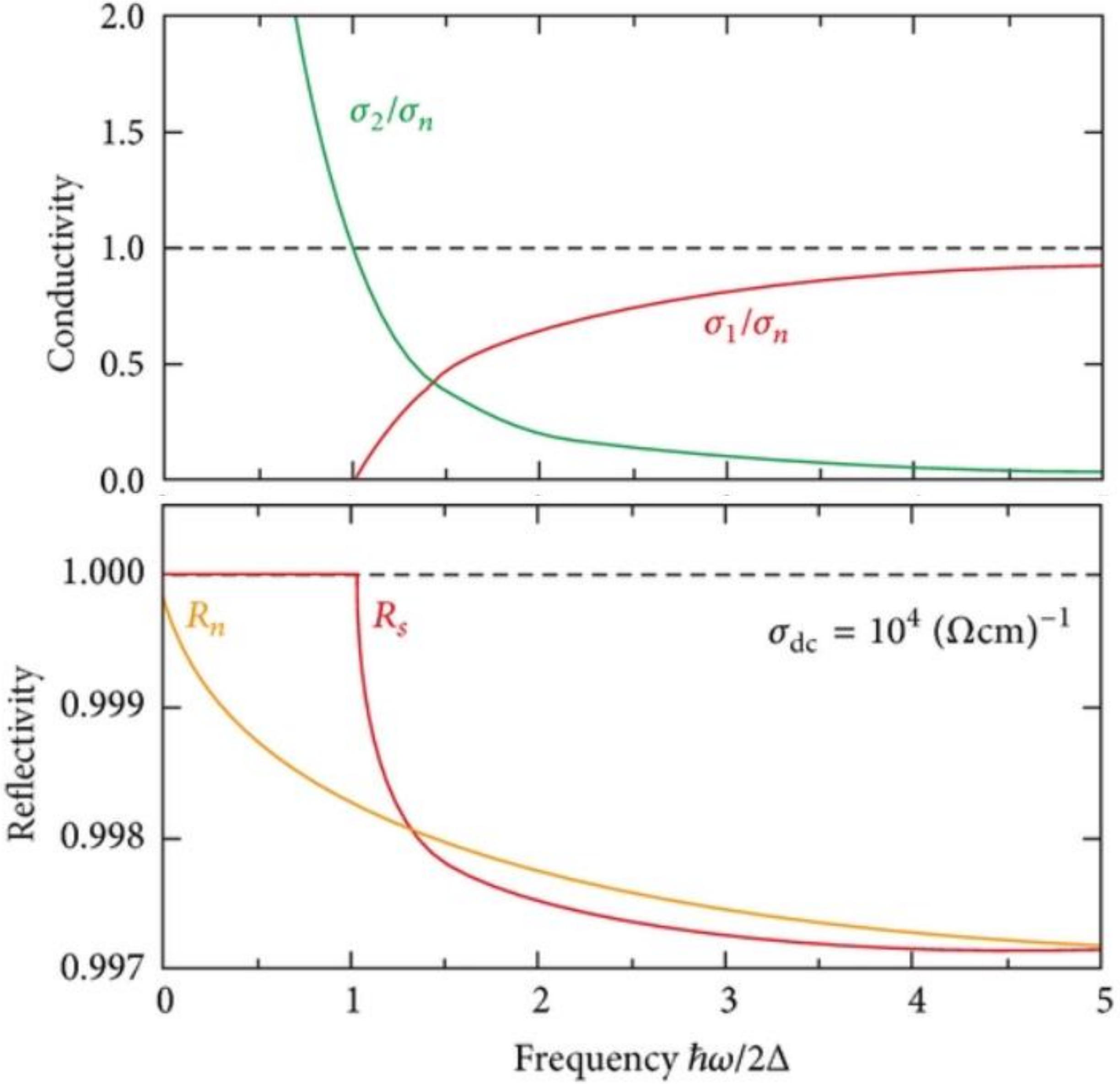
Alkalmazott szilárdtestfizika: $\frac{\mathrm{d}I}{\mathrm{d}V} \sim T \cdot g_{\mathrm{N}}(\varepsilon_{\mathrm{F}}) \int \mathrm{d}\varepsilon\, g_{\mathrm{S}}(\varepsilon) \underbrace{f_{\mathrm{N}}'(\varepsilon - eV)}_{\sim -\delta(\varepsilon - eV)} \sim T \cdot g_{\mathrm{N}}(\varepsilon_{\mathrm{F}}) g_{\mathrm{S}}(\varepsilon - eV)$



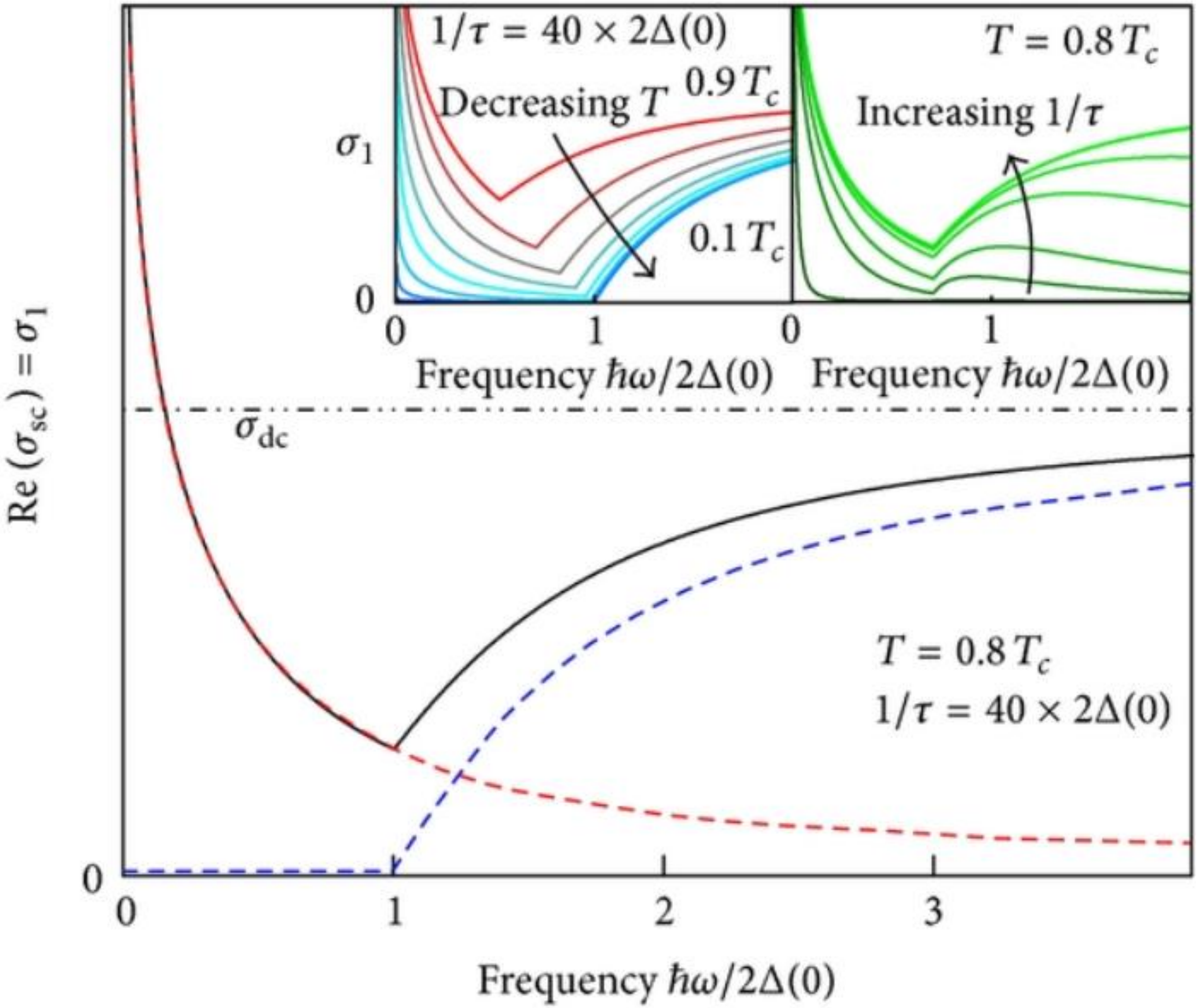


M. Dressel, Advances in Condensed Matter Physics 2013, 104379

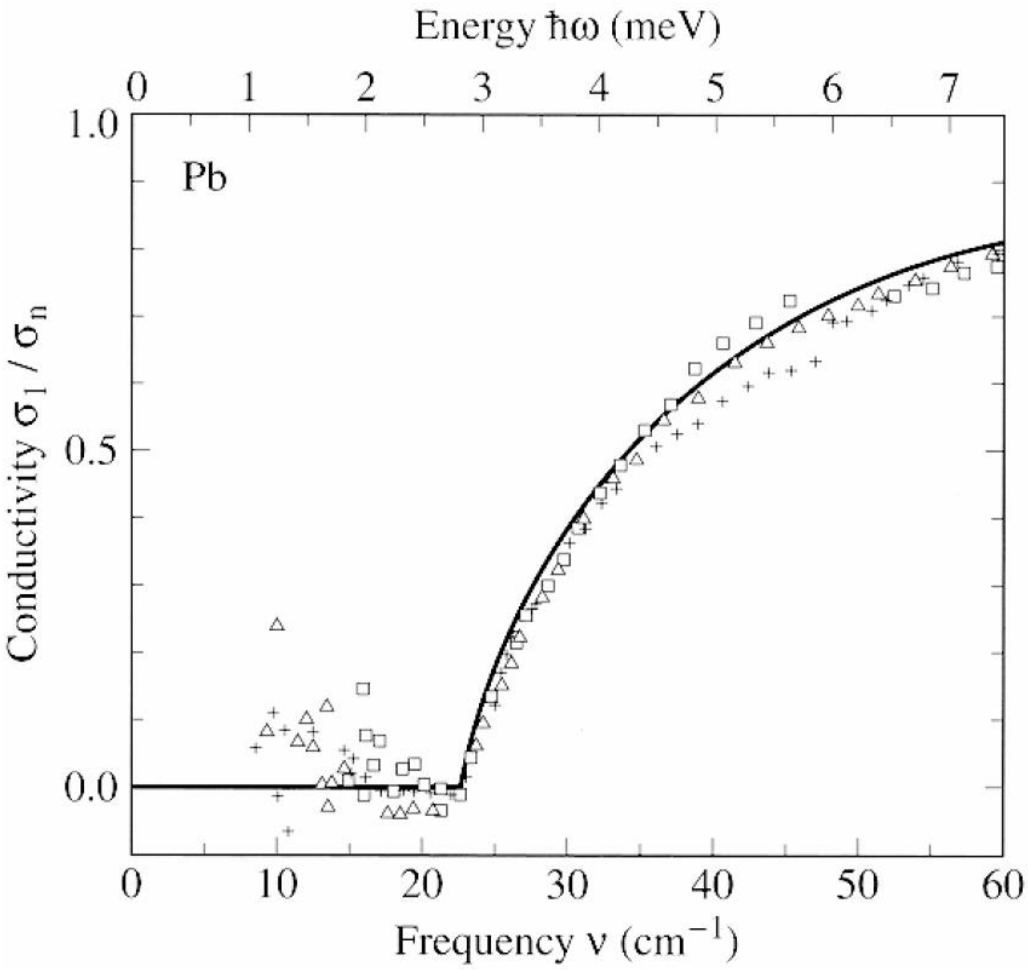
Matrix element: coherence effect



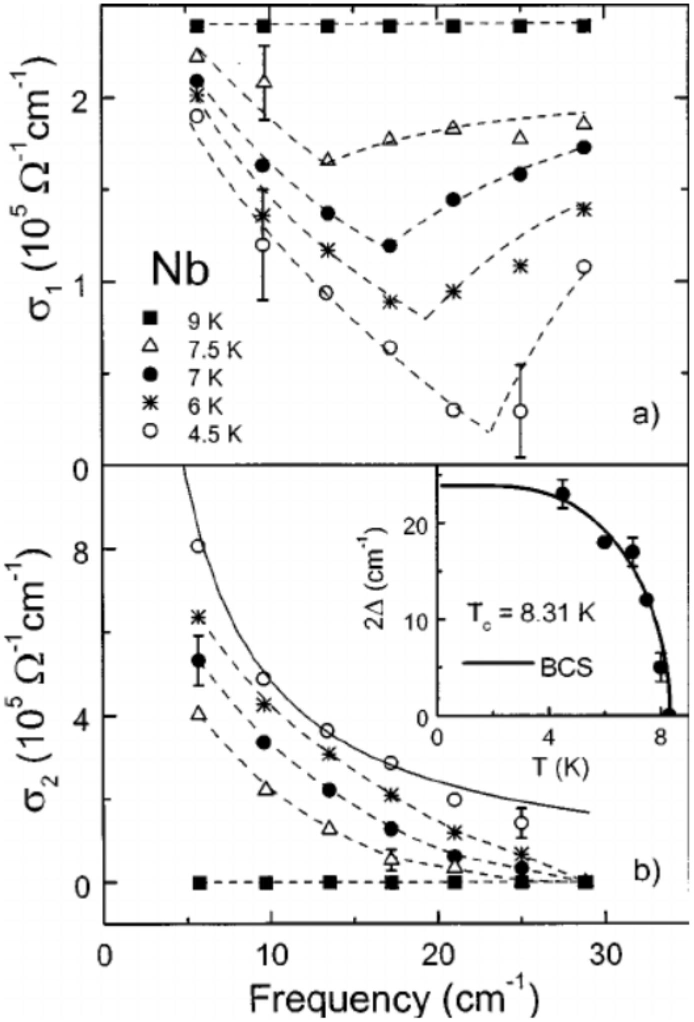
Mattis-Bardeen equation:
$$\frac{\sigma_1(\omega,T)}{\sigma_n} = \frac{2}{\hbar\omega}\int_{\Delta}^{\infty} \frac{\left[f(\mathcal{E}) - f(\mathcal{E}+\hbar\omega)\right]\left(\mathcal{E}^2+\Delta^2+\hbar\omega\mathcal{E}\right)}{\left(\mathcal{E}^2-\Delta^2\right)^{1/2}\left[(\mathcal{E}+\hbar\omega)^2-\Delta^2\right]^{1/2}}d\mathcal{E}$$
$$+\frac{1}{\hbar\omega}\int_{\Delta-\hbar\omega}^{-\Delta} \frac{\left[1-2f(\mathcal{E}+\hbar\omega)\right]\left(\mathcal{E}^2+\Delta^2+\hbar\omega\mathcal{E}\right)}{\left(\mathcal{E}^2-\Delta^2\right)^{1/2}\left[(\mathcal{E}+\hbar\omega)^2-\Delta^2\right]^{1/2}}d\mathcal{E}$$



Pb at 2K
Phys. Rev. **165** 588 (1968).

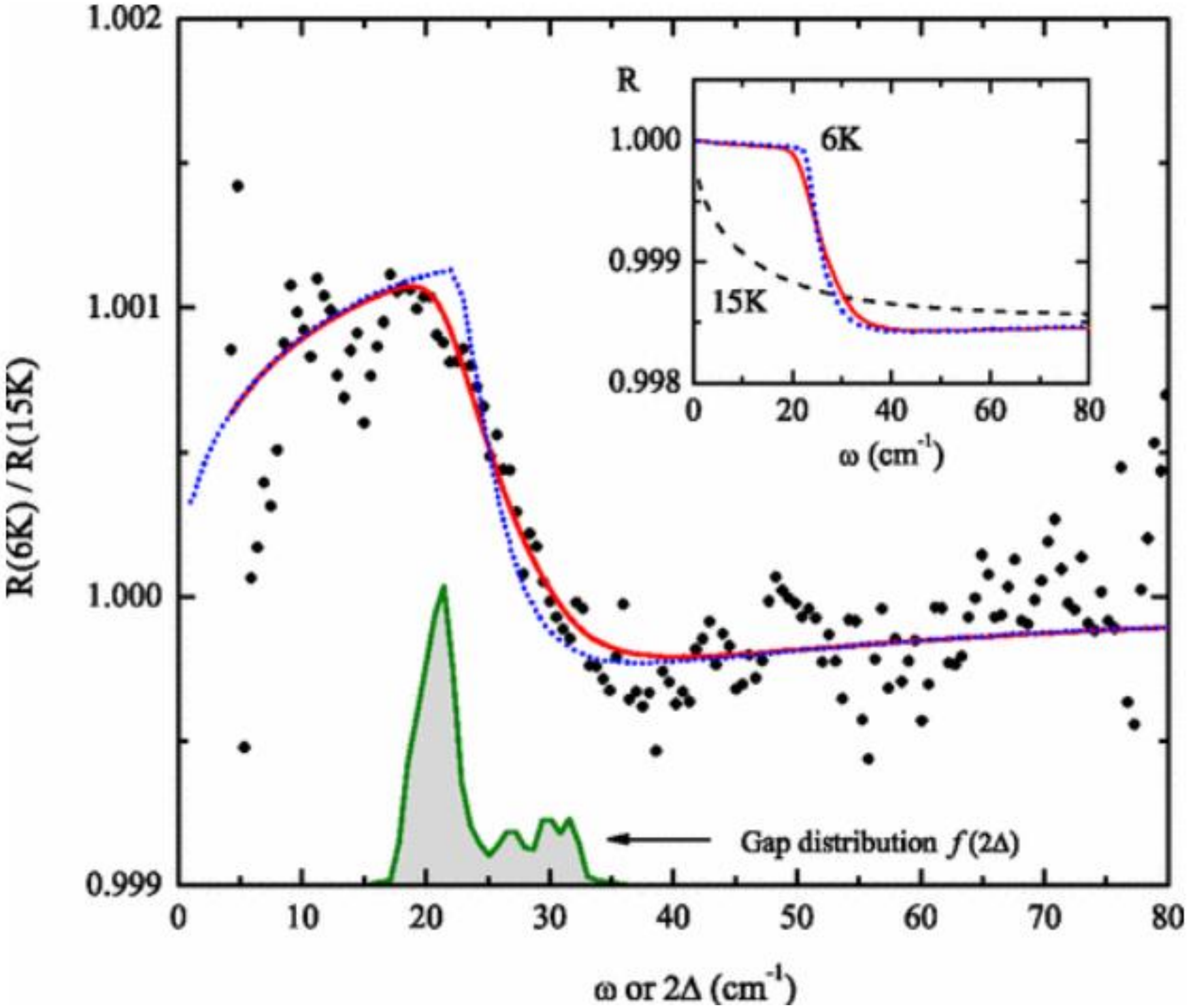


Nb
Phys. Rev. B **57** 14416 (1998).

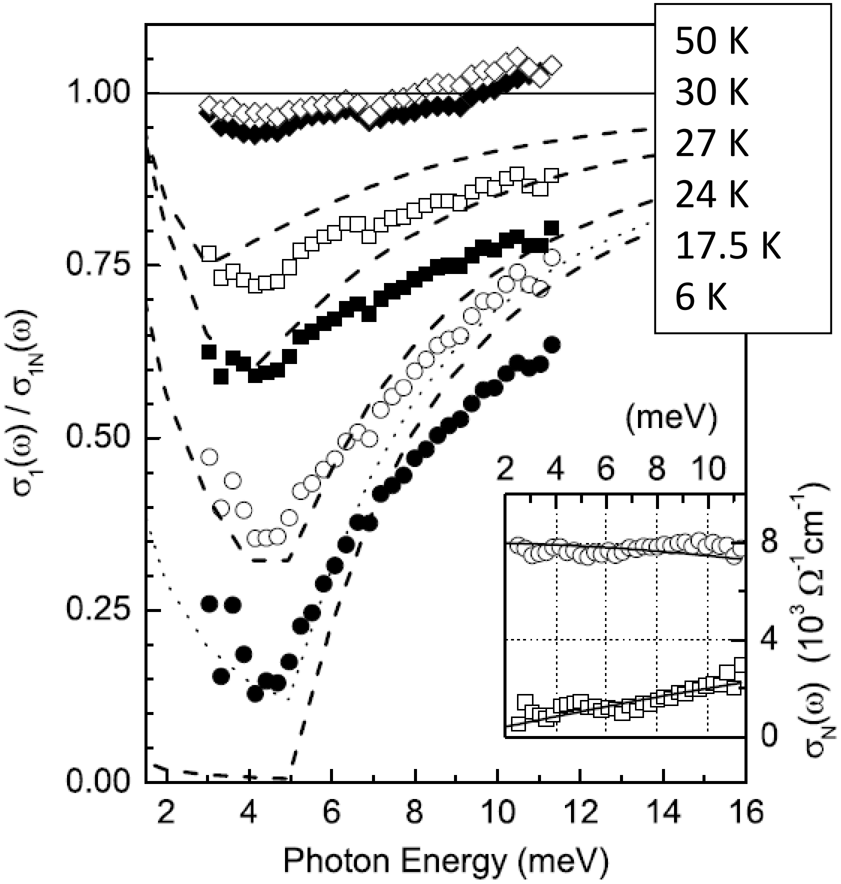


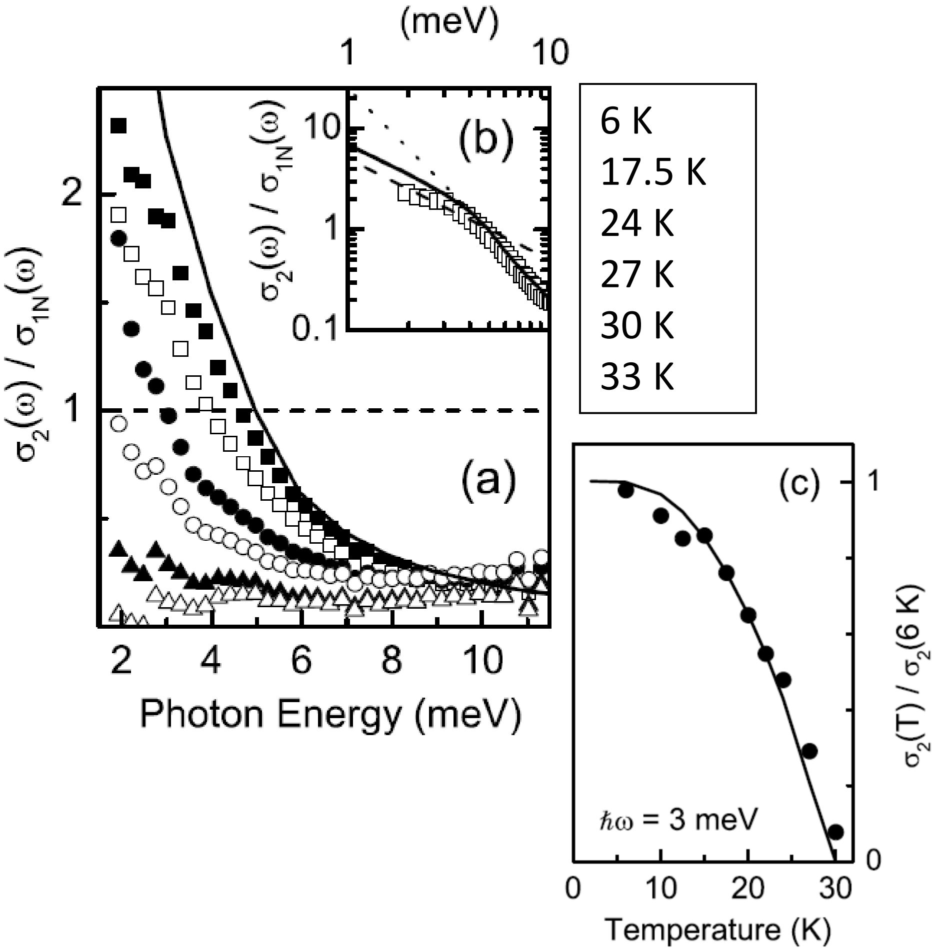
CaC6

Phys. Rev. B **78**, 041404(R) (2008).



MgB2





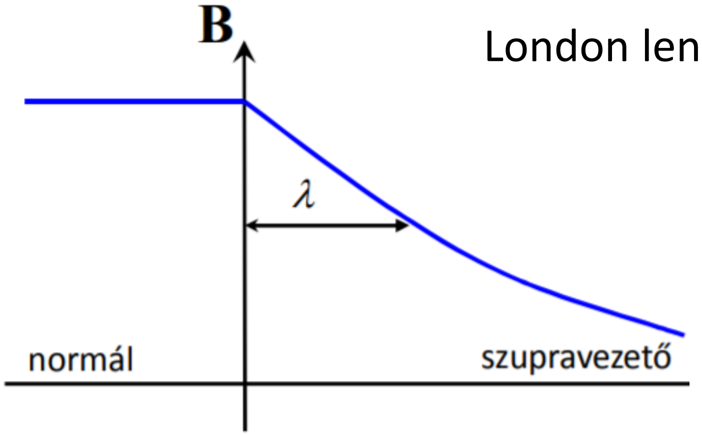
BCS fit: $2\Delta_o$=5 meV

Gyenge csatolás: $2\Delta_o=3.5k_BT_C$=9 meV

Gap alatt kvázirészecske gerjesztés

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

Meissner effect:



London length:

$$\lambda = \sqrt{\frac{m^*}{\mu_0 n_s {e^*}^2}}$$