Shining the Light on Ultra-Thin Films

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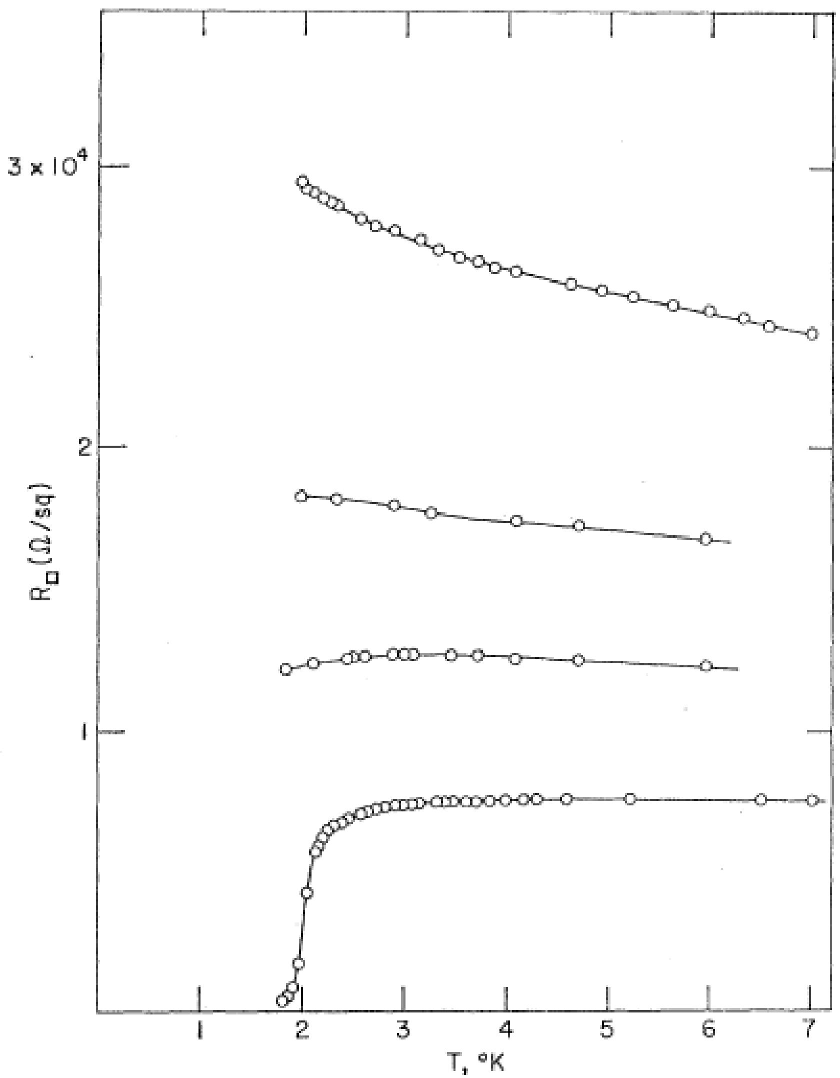
Insulator to Superconductor (I/S) Transition



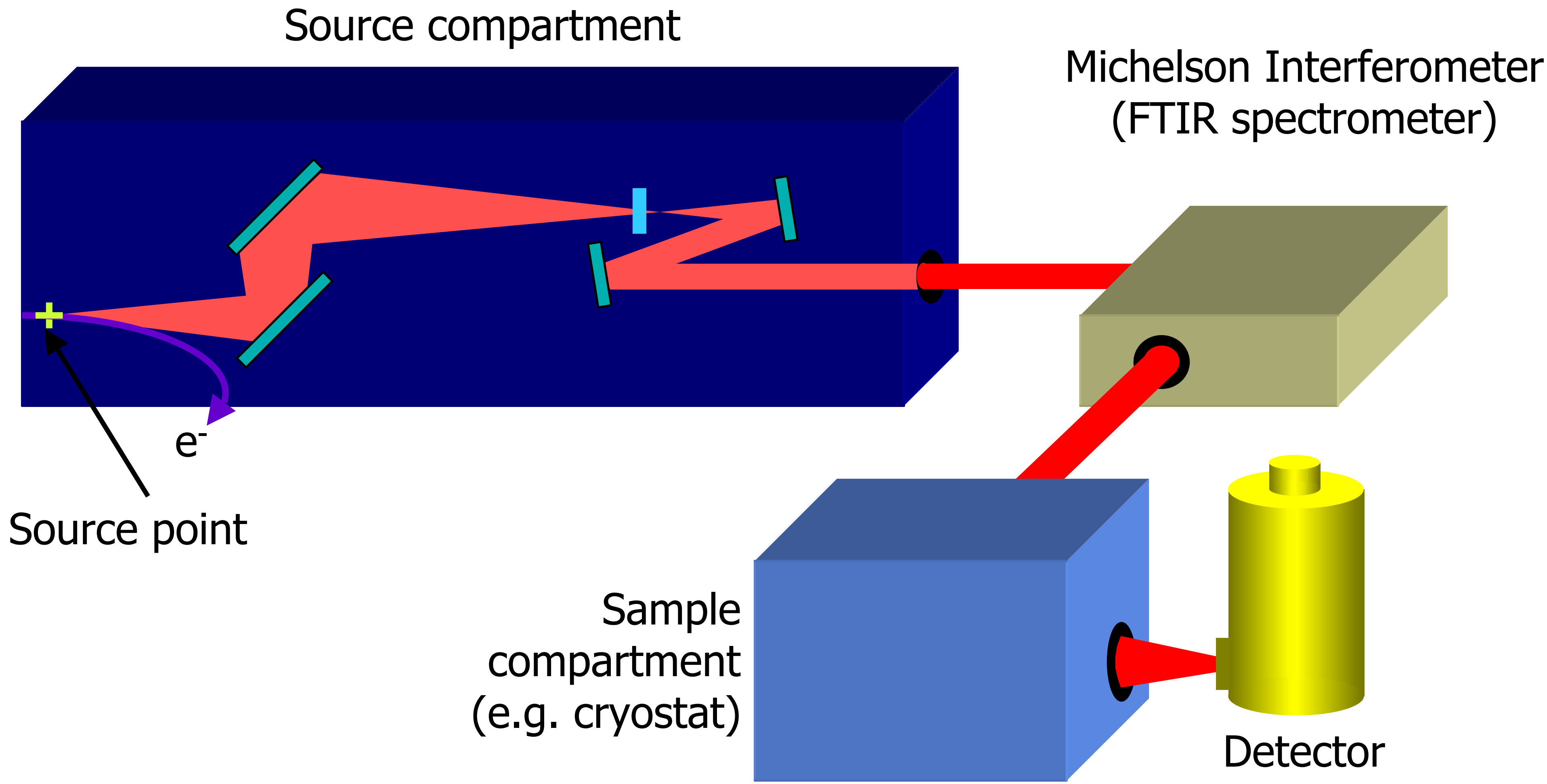
M. Strongin *et al.* Phys. Rev. B **1,** 1078 (1970).

Collaborations

- ➔ **Myron Strongin (BNL)**
- ➔ **Chris Homes (BNL)**
- ➔ **Larry Carr (NSLS, BNL)**
- ➔ **Yosef Imry (Weizmann)**

- Ultra-thin films have a similar phase diagram as high-T_c cuprates;
- Ultra-thin films are also model nano-systems showing dimensional crossovers from zero to 2D to 3D;
- Optical spectroscopy, particularly FTIR, can shed new light on ultra-thin films and other nano-systems.

FTIR Experimental Setups

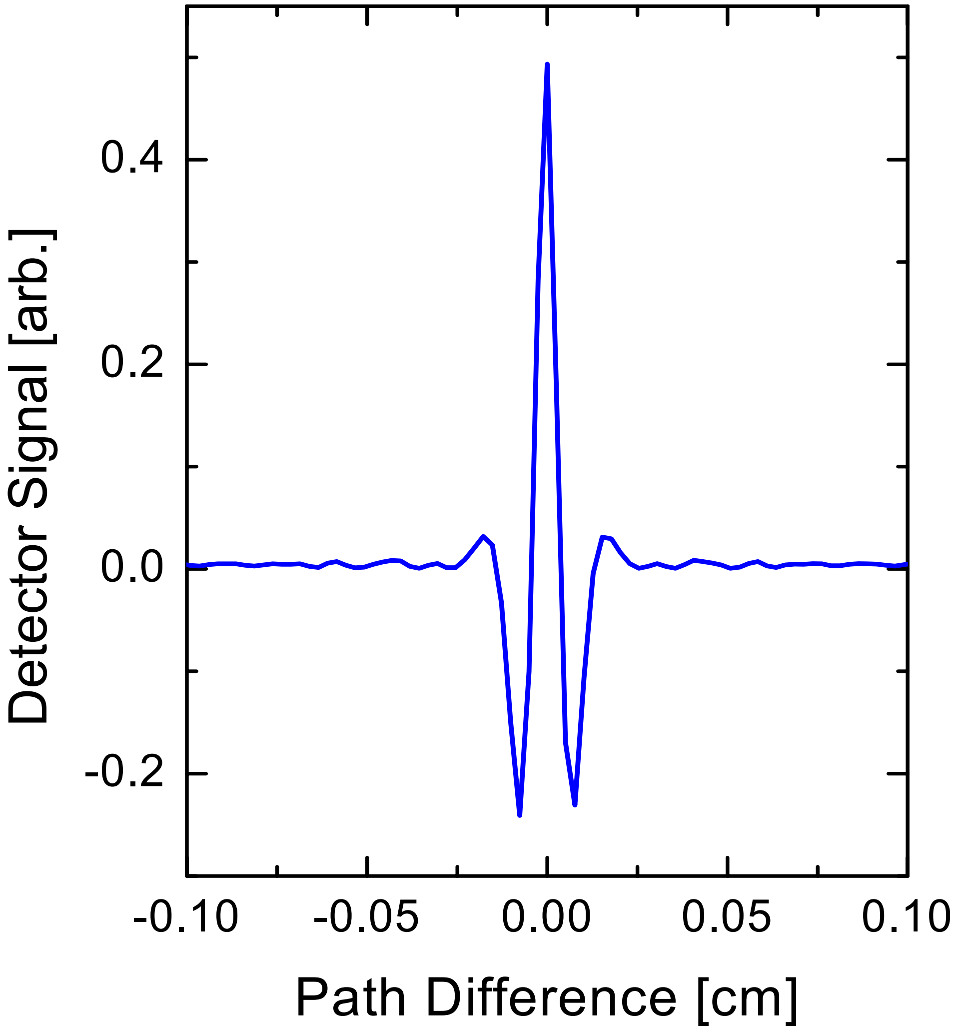


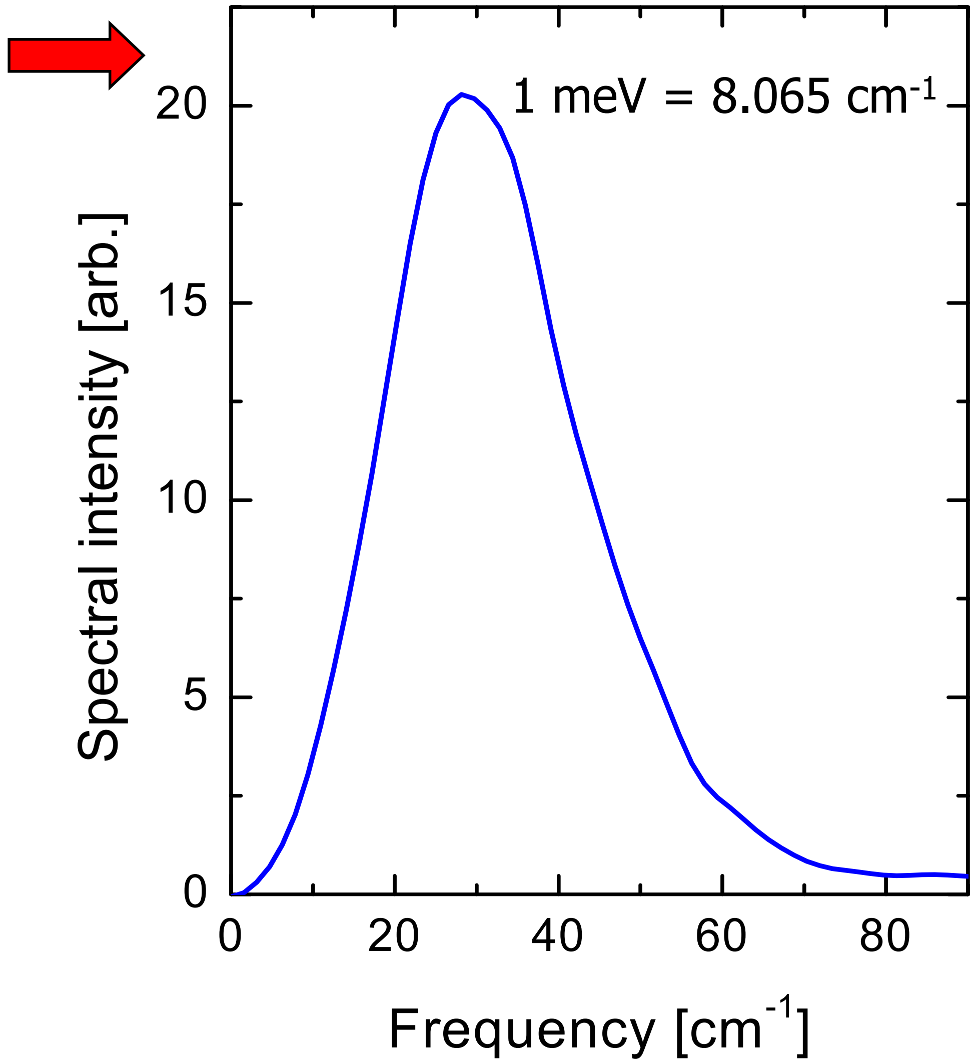
FTIR Spectroscopy

Interferogram

Fourier Transform

Spectrum





National Synchrotron Light Source

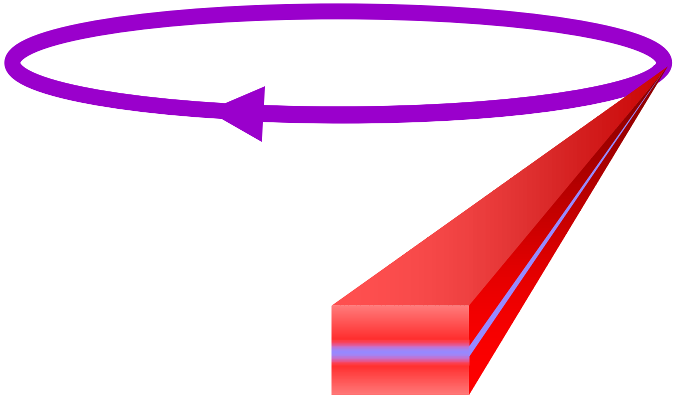
2.8 GeV (x-ray) and 800 MeV (VUV) electron storage rings.

6 beamlines on VUV ring dedicated to infrared measurements.

X-ray ring

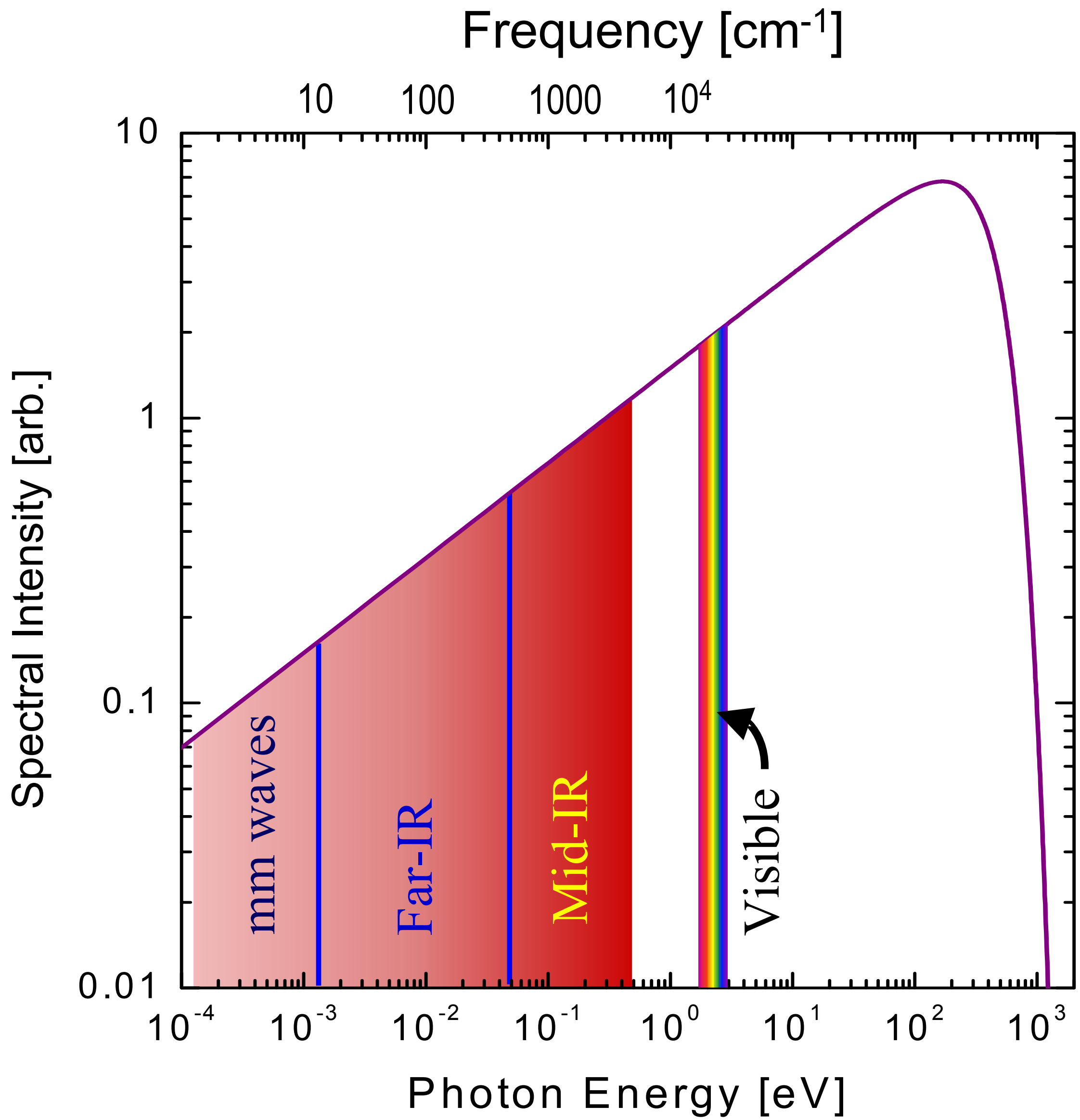
VUV ring

Infrared Synchrotron Radiation

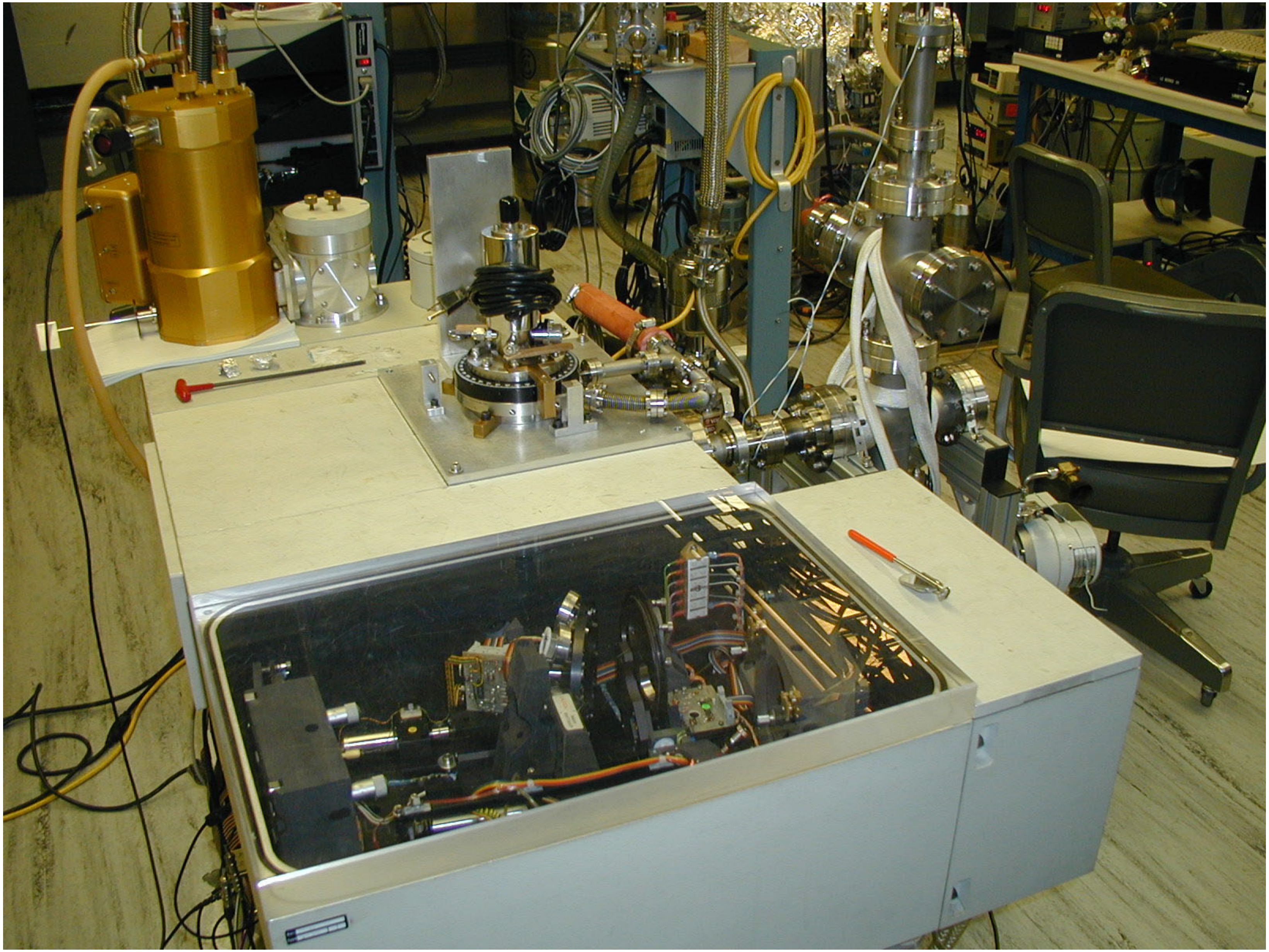


- "White" source
- High Brightness
- Pulsed (100s of ps)

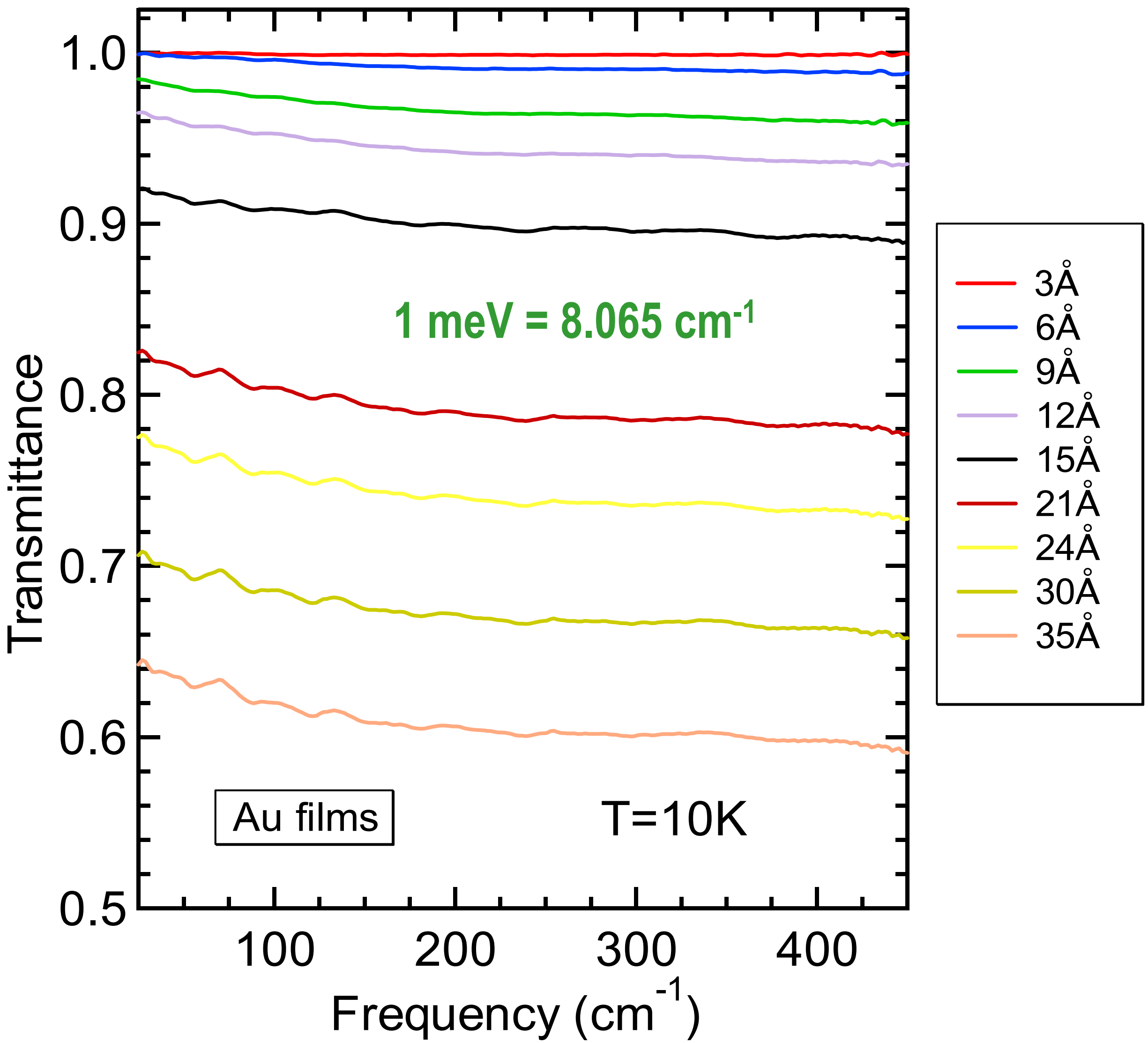
(1 eV = 8065 cm^{-1})
1 cm^{-1} = 30 GHz
1 cm^{-1} = 1.44 Kelvin



Bruker 113 with the Thin Film Deposition Rig



Infrared Transmittance of Ultra Thin Films: Au Films

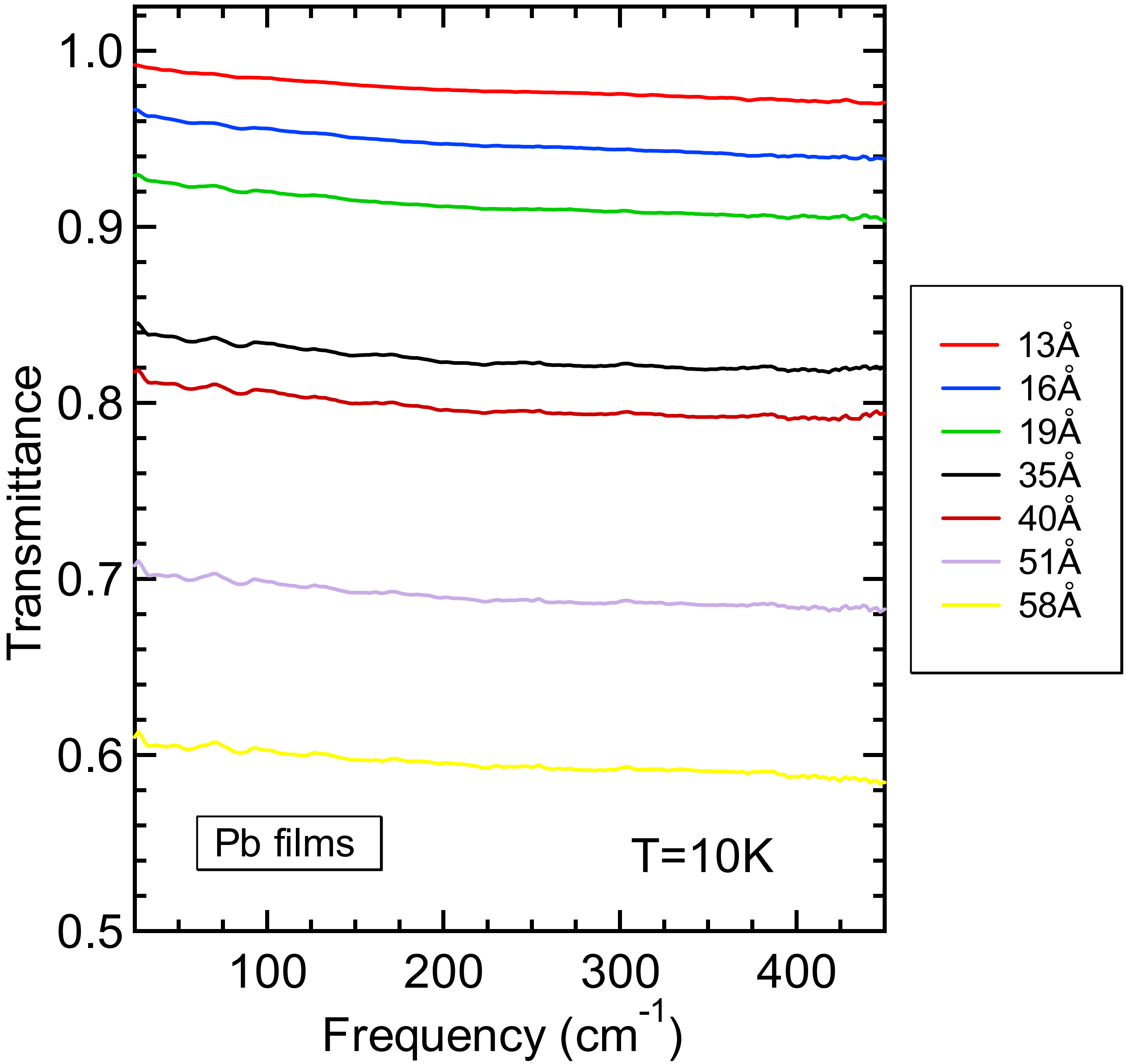


J.J. Tu *et al.* Phys. Rev. Lett. **90**, 017402 (2003).

Experimental Details:

- Ultra-thin Metal films are deposited on Ge-coated (~ 10Å) Si<111> substrates held at 10K;
- The metal films are deposited *In situ* in ultrahigh vacuum ($<10^{-8}$ torr);
- A similar Si<111> substrate is used as the reference at all times.

Infrared Transmittance of Ultra Thin Films: Pb Films



Data Analysis:

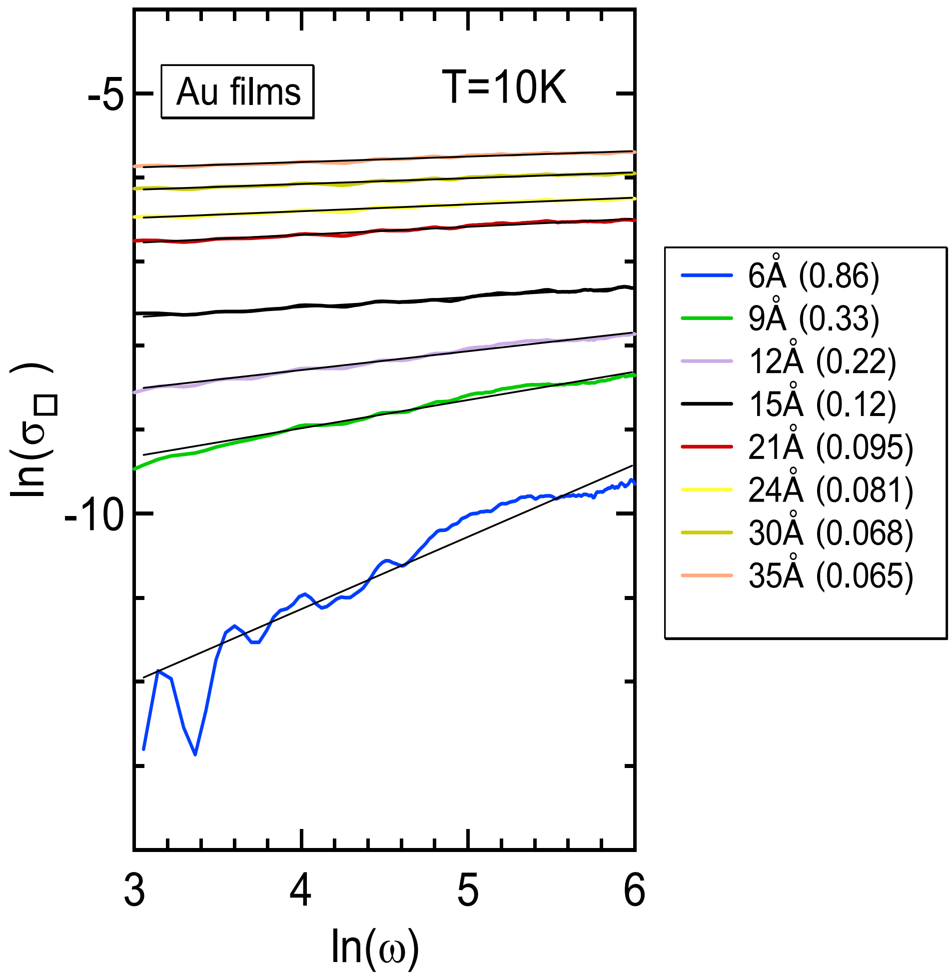
- Optical transmission of thin films is given by the Tinkham formula:

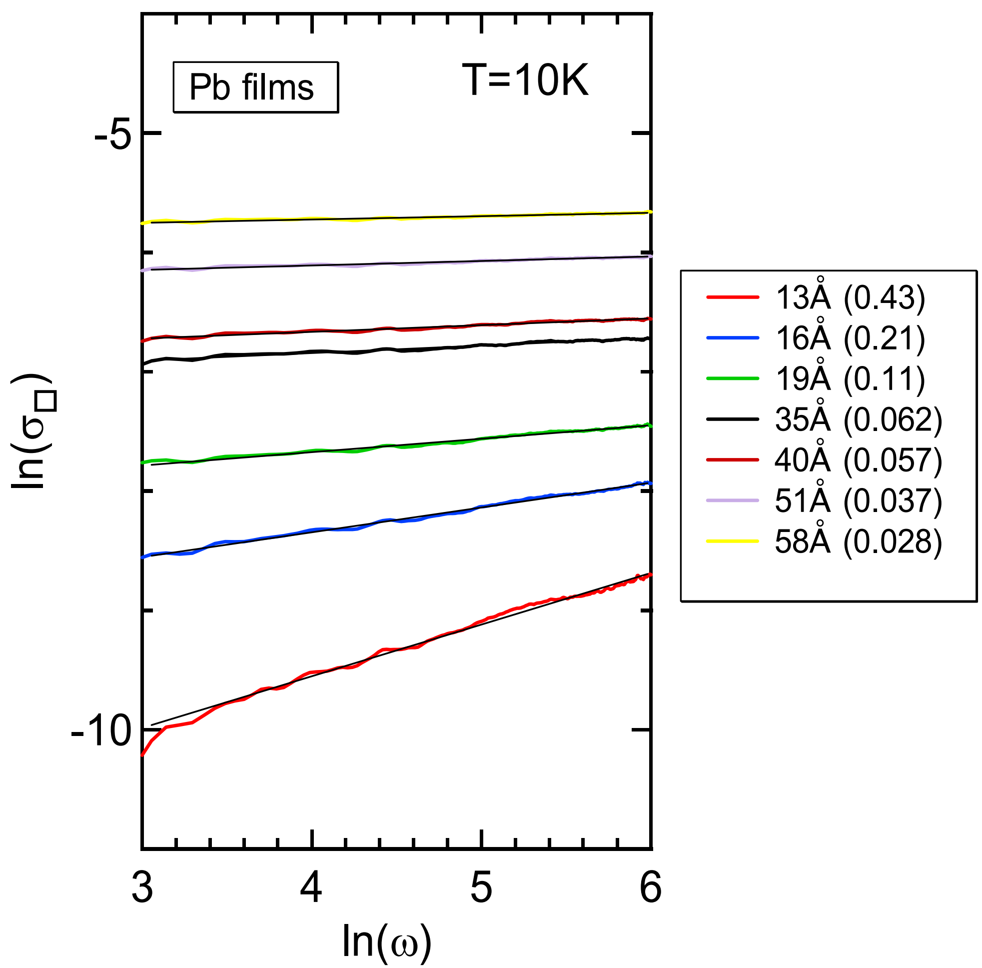
$$T = 1 \Big/ \left| 1 + \tilde{\sigma}_{\square} \frac{Z_0}{n+1} \right|^2$$

- For most cases, $\sigma_{\square}''$ is neglected since $\sigma_{\square}'' \ll (n+1)/Z_0$:

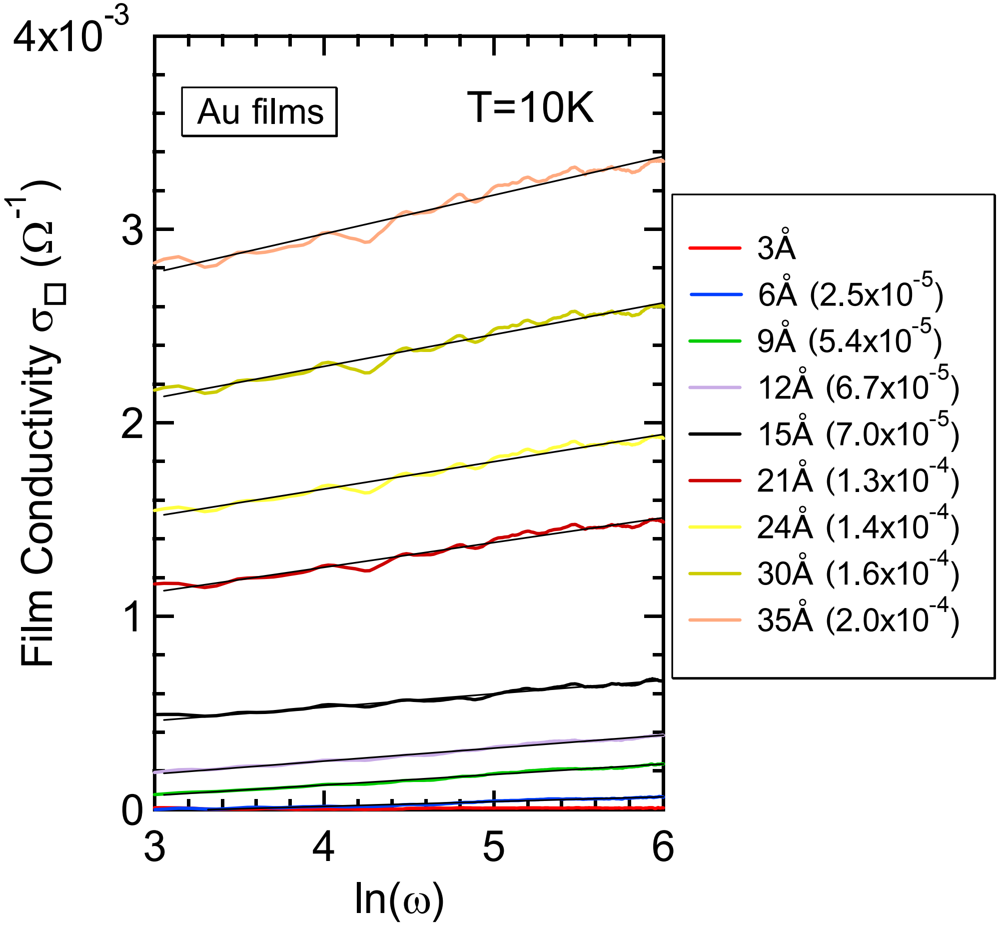
$$T = 1 \Big/ \left| 1 + \sigma'_{\square} \frac{Z_0}{n+1} \right|^2$$

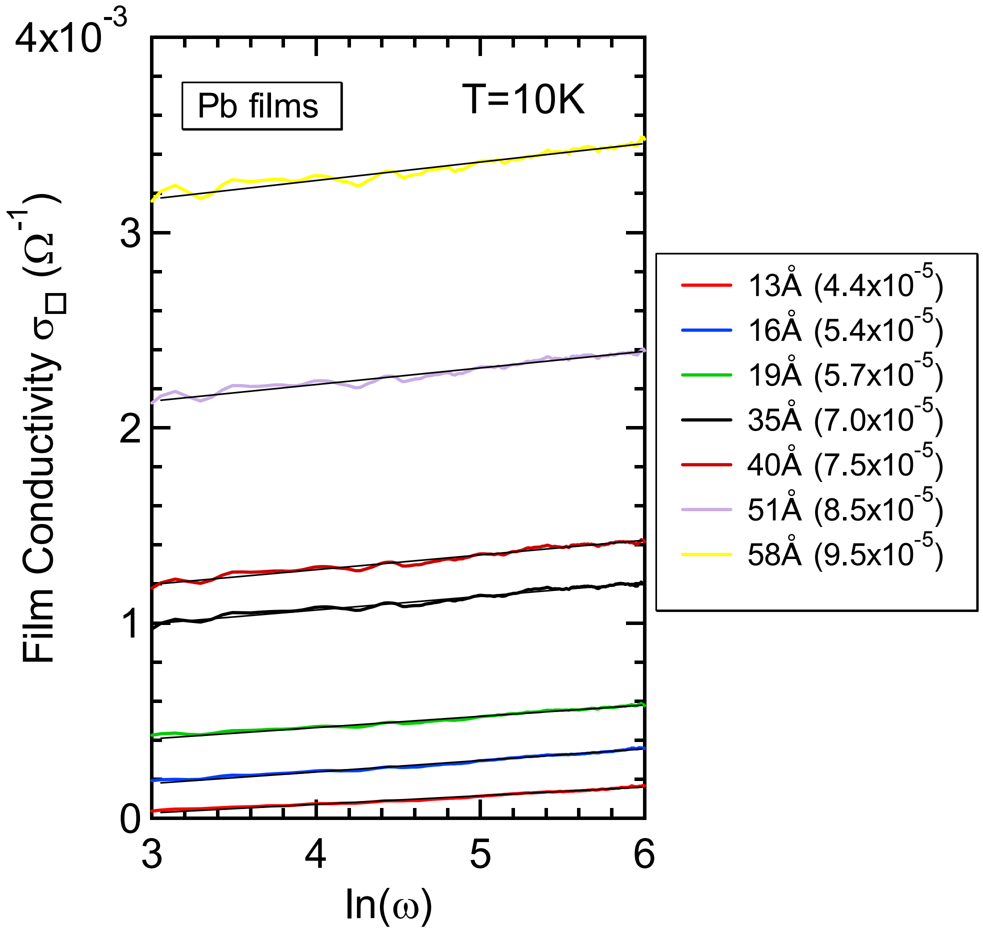
Frequency Dependence of Optical Conductivity





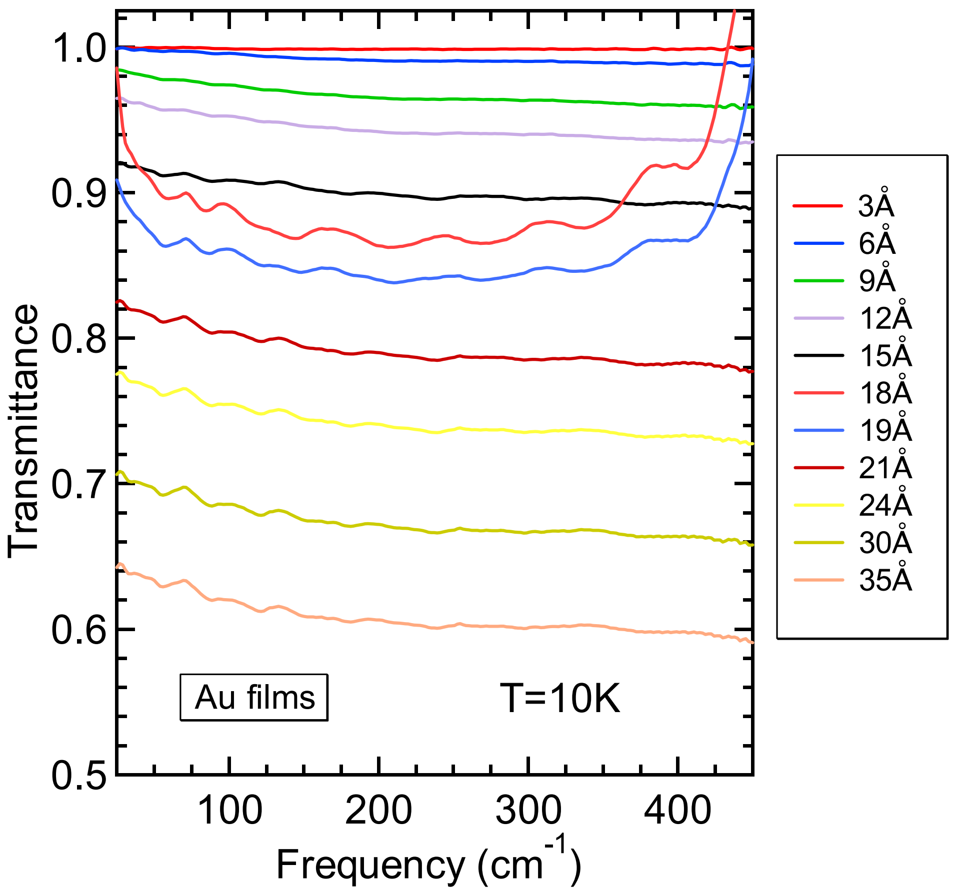
Frequency Dependence of Optical Conductivity

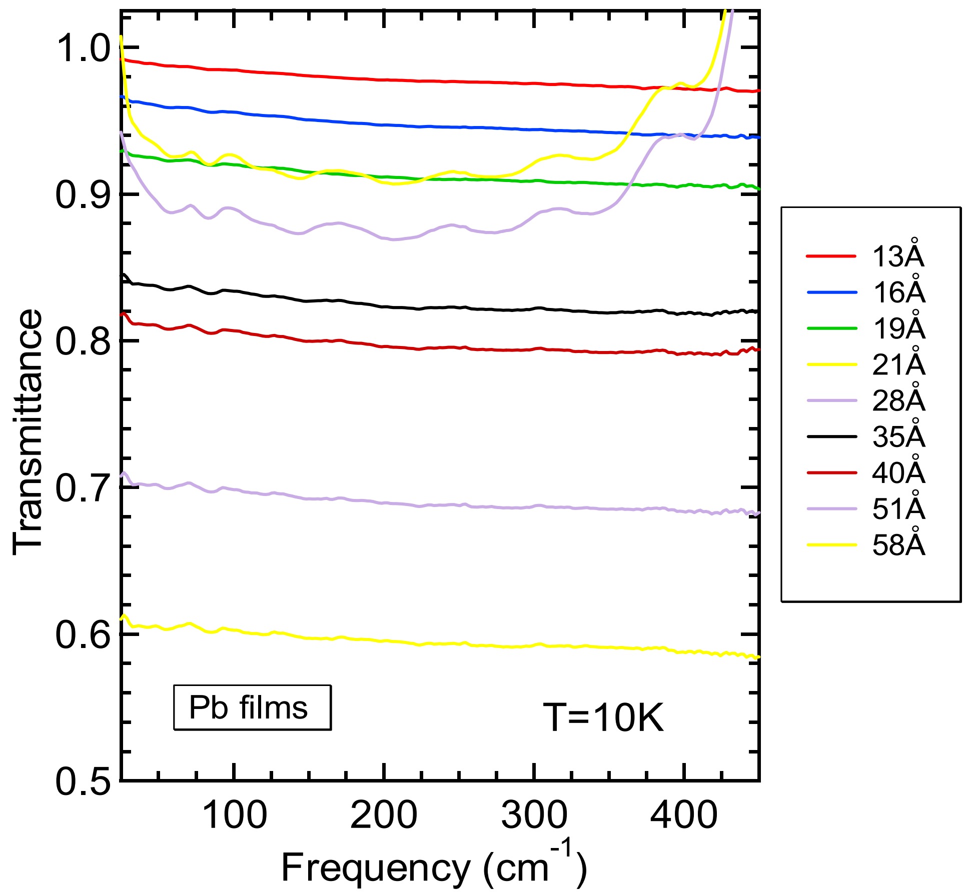




2-D weak localization theory predicts a slope of 1.24×10^{-5}.

Anomalous Transmittance of Ultra Thin Films

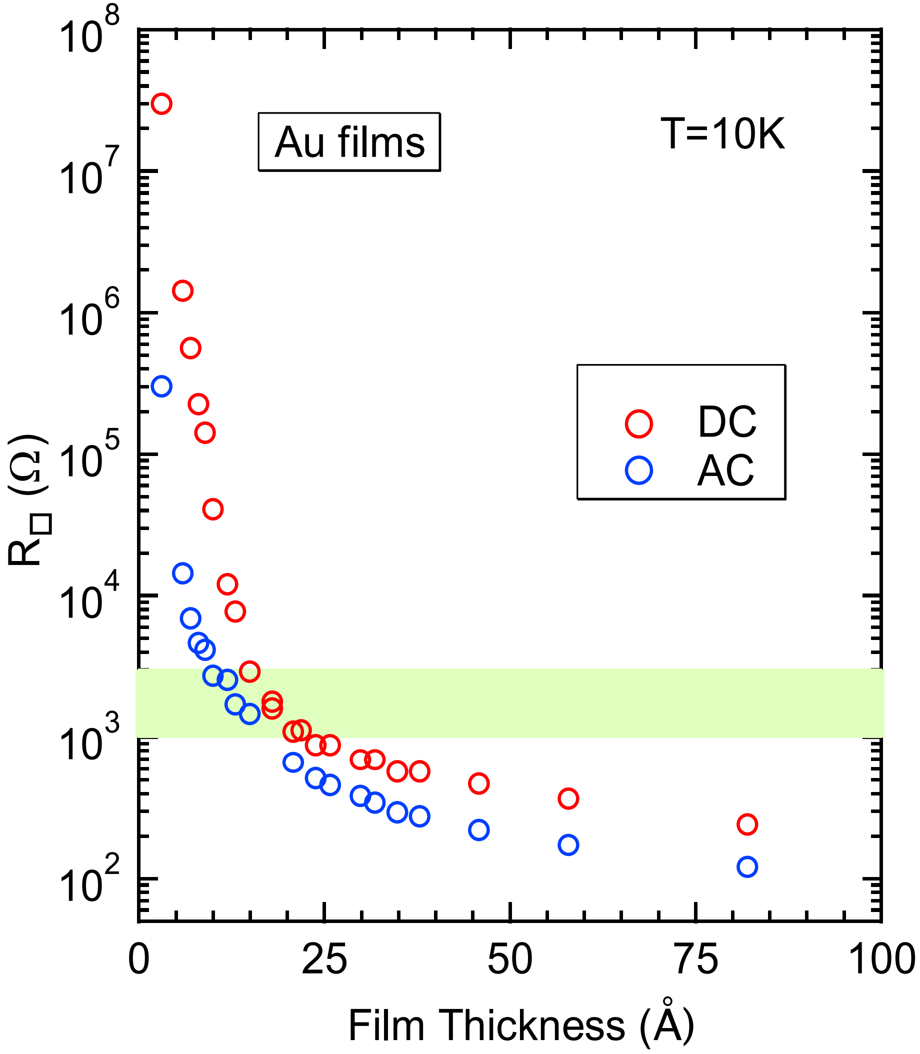


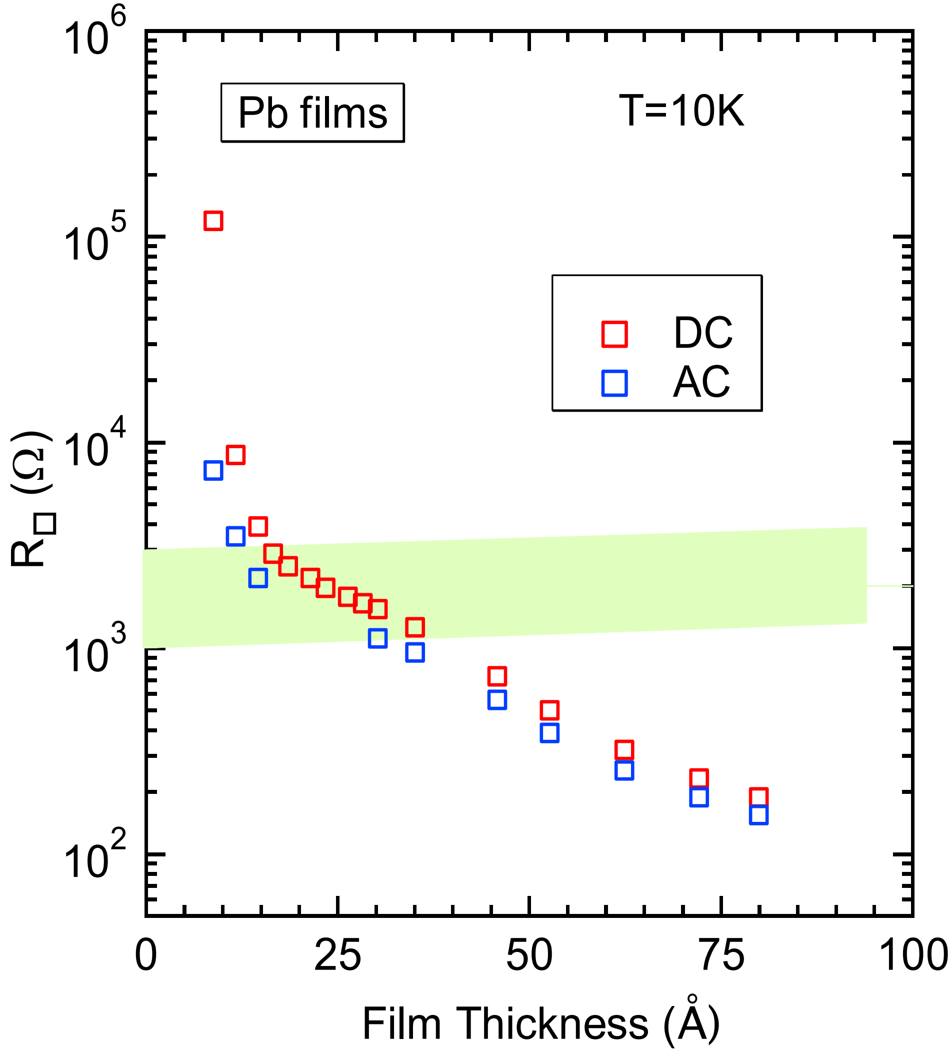


The anomalous transmittance is due to **interference** effects of the film and substrate;

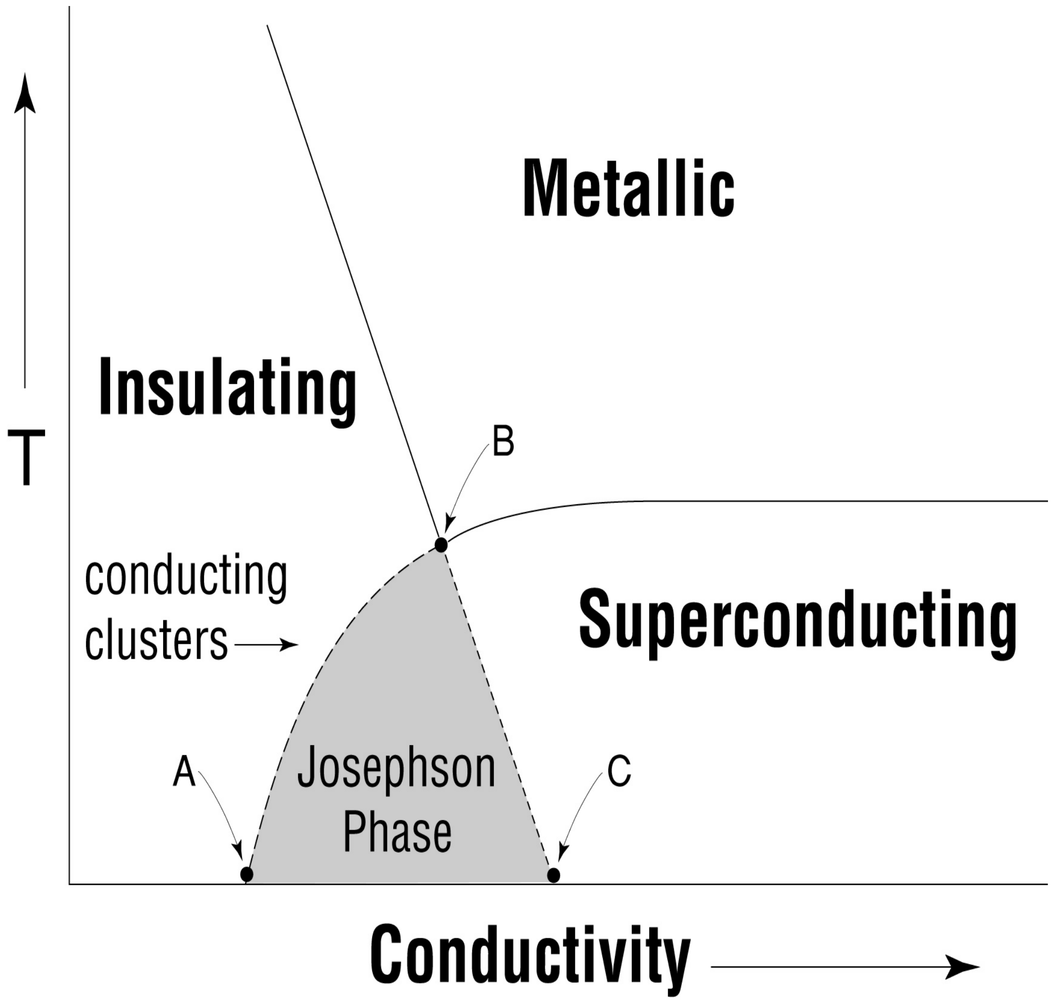
This effect is caused by the dielectric anomaly near the **insulator-metal (I/M)** transition at ~ 20 Å or between ~ 3 kΩ.

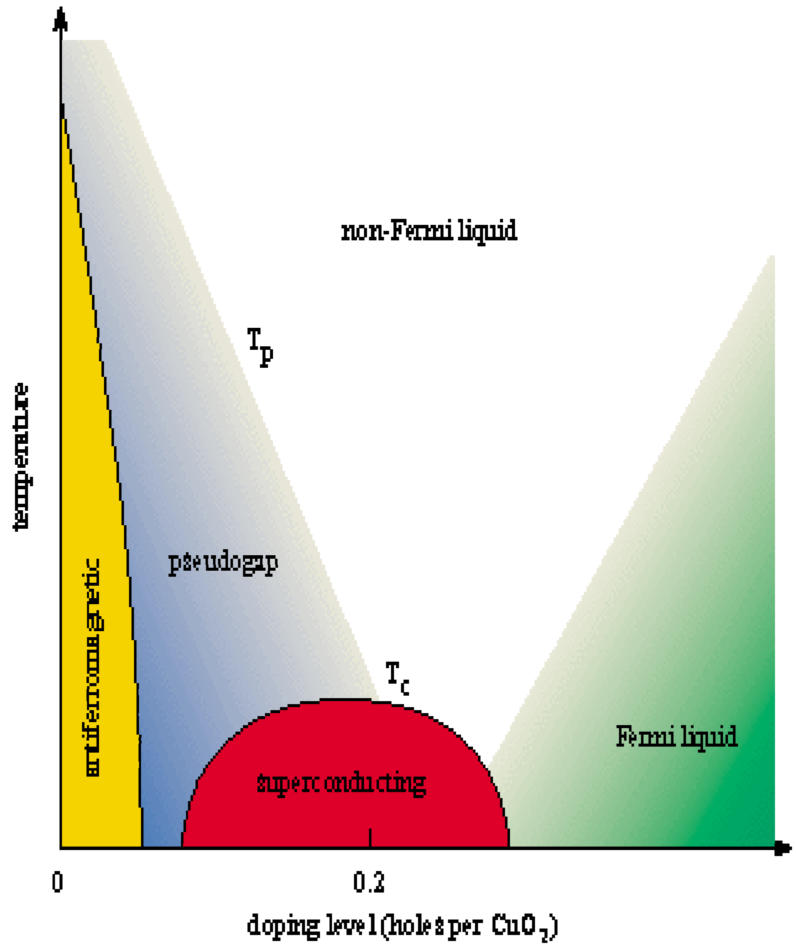
DC Conductivity of Ultra Thin Films





Is There A "Josephson" Phase ?





Underdoped Optimally doped Overdoped

J. J. Tu, M. Strongin and Y. Imry "*An Inhomogeneous Josephson Phase Near the (Super) Conductor-Insulator Transition*", cond-mat/0405625 (2004).

Bruker 66 Spectrometer Coupled with a Magnet

- Bruker 66 v/S spectrometer has a wide dynamic range (1meV – 6 eV) and superb long term stability;

- Oxford Spectromag is a very compact superconducting split magnet with easy optical access that can go up to 10T.

Conclusions

- Anomalous transmittance is observed at critical thickness of about 20 Å for both Au and Pb films; and this is due to the insulator-metal (I/M) transition;

- Ultra thin metal films could be used as model systems for the study of high temperature superconductivity;

- Optical spectroscopy reveals rich information on the nature of ultra thin metal films and can be used as a contactless probe for nano-systems in general.