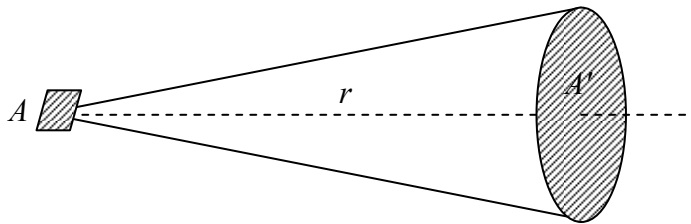


## Black Body Radiation

References: P.A. Tipler, "Modern Physics," pp. 102-107 (Worth Publishers, Inc., NY, 1978).

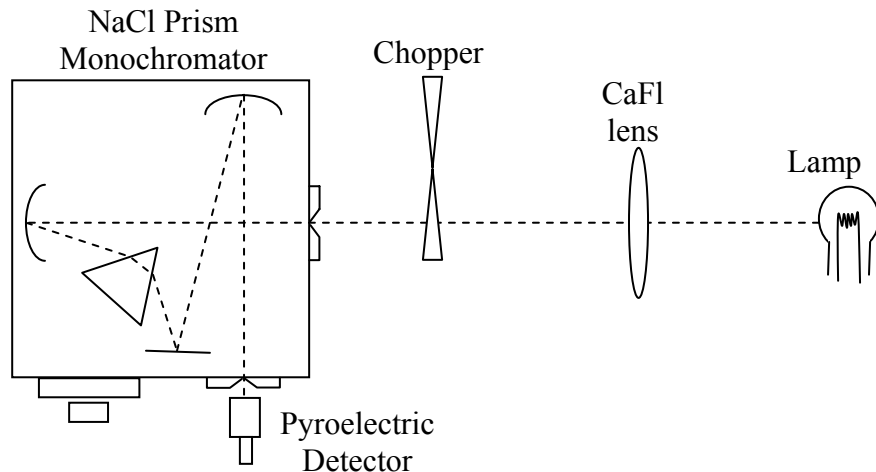
Read carefully the material in this reference or any other Modern Physics text. The goal of this experiment is measurement of the spectral distribution from a black body. The black body to be used is not a cavity (which is a very good black body) but the tungsten filament of a projection lamp (which is probably not black, i.e. the emissivity is less than one – and which has a thin glass envelope surrounding it). Perhaps you may choose to determine how close to being a black body the lamp is.

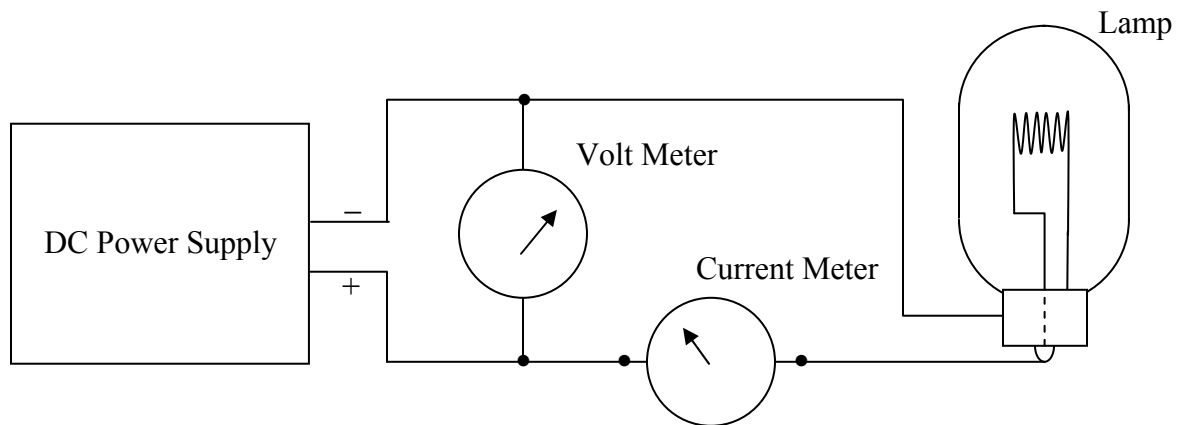
If  $U$  is the radiation density in equilibrium with the surface of a black body at temperature  $T$ , then the radiation is also at that temperature. The power radiated away from a surface  $A$  of unit area is then  $R = \frac{1}{4}cU$ . This power is radiated into the half space to the right of  $A$ , a solid



angle of  $2\pi$  steradians. If we place a detector of area  $A'$  a distance  $r$  from  $A$  along the normal to  $A$ , the power received at  $A'$  is  $P = \frac{cUA}{4} \left( \frac{A'}{r^2} \frac{1}{2\pi} \right)$ . The factor in parentheses is the ratio of the solid angle subtended by the detector to the total solid angle  $2\pi$  into which thermal emission takes place.

In our experiment, we will insert a number of additional elements between the source and the detector. The physical layout and lamp schematic are shown below.





The radiation detector is an InfraTec LIE-316-# pyroelectric detector with a CaF<sub>1</sub> window. This is a 2mm square lithium-tantalate capacitor, one plate of which is a blackened surface which approximates a black body absorber at radiation wavelengths from 400 to 10,000nm. The dielectric of this detector is permanently polarized; however, the magnitude of the polarization is temperature dependent. Therefore, a time dependent illumination of the detector changes its temperature and produces a charging current in an external circuit. Since the responsivity of the detector and its built in circuitry is only  $150\mu\text{V}/\mu\text{W}$  of power, this very small signal is amplified by the first stage *ac* input amplifier of the Lock-In Amplifier. This amplifier has built into it a 60 hertz notch filter, designed to reject the 60 hertz components in the input signal. Even though the signal has been amplified and much of the 60 hertz “noise” removed, under conditions of the experiment, the signal is still buried in random noise. The next stage of the Lock-In is a phase sensitive detector which extracts the detector signal from the noise (refer to your notes from the Lock-In experiment).

The light chopper modulates the light from the lamp and generates a reference signal at the chopping frequency. The phase sensitive detector chops the amplified input signal at the frequency of the reference signal. Since both are at the same frequency, the resultant signal waveform is “rectified”, and a *dc* voltage is produced. This *dc* voltage is a maximum when both signal and reference are exactly in phase. An oscilloscope can be used to monitor either the chopper reference signal or the amplified *ac* signal (before phase sensitive detection).

## Procedure

1. Familiarize yourself with all of the equipment, and read the appropriate manuals.
2. Cautions:
  - a. The NaCl prism is moisture sensitive, therefore do not open up the spectrometer.
  - b. The cables generate large electrostatic signals when moved, therefore don't move them.

- c. The lock-in overload light indicates when the signal from the *ac* amplifier is too large for the *psd*. The phase quadrant and phase adjust controls shift the phase of the signal relative to the reference. The phase control should be adjusted for maximum signal.
- Line up the lamp *L* and chopper *C* and turn on both (do not exceed 6 Amps for the lamp current). Connect the chopper reference to the lock-in reference input. Using a tee, you can also connect this reference signal to one input of the CRO.
  - Line up the lamp and monochromator and turn the lamp on (start with about 5.5 A). Set the spectrometer at 0.589 $\mu\text{m}$  and adjust the position of the lamp until the image is blinding. Insert the pyroelectric detector and connect it to the lock-in signal input. Set the monochromator to around 1.5-2.0  $\mu\text{m}$ . Adjust the sensitivity control to give a reading on scale, and the phase control for a maximum reading on the *psd* meter. Set the time constant to 1 or 3 seconds. Observe the lock-in output with and without the various notch filters. Why is it desirable to operate with the filters in? Play with the chopping frequency to determine the optimum value (best signal to noise ratio). Record what you learn.
  - Slowly scan the spectrum from .589 $\mu$  to about 8 $\mu$ , and roughly locate the region of peak intensity (remember that a 1 or 3 second time constant limits the response time of the system). Record intensity values which will enable you to plot the full spectrum, with special emphasis on data near the peak. Be sure to record both lamp current and voltage. Decrease the lamp current to  $\sim 4.2$  A and repeat the above spectral scan.
  - Plot the intensities recorded with the higher lamp current as a function of wavelength. Determine the filament temperature for this lamp current using Wien's Displacement Law  $\lambda_m T = 2.898 \times 10^{-3} \text{ m} \cdot \text{K}$ . Then plot the theoretical energy spectral distribution, derived by Planck,

$$U(\lambda)\Delta\lambda = \frac{8\pi hc \lambda^{-5} \Delta\lambda}{\exp(hc / \lambda kT) - 1}.$$

Here  $\Delta\lambda$  is the bandpass of the spectrometer,  $\lambda$  is wavelength,  $h$  is Planck's constant,  $c$  is the speed of light,  $k$  is Boltzmann's constant and  $T$  is the Kelvin temperature. Since  $\Delta\lambda$  is approximately constant (it depends on the slit widths and the dispersion of NaCl), calculation of  $\lambda^{-5} [\exp(hc / \lambda kT) - 1]^{-1}$  is all that is required. The theoretical curve should be normalized to the experimental curve at the maximum. How good is the agreement between the shapes of the experimental and theoretical curves? Can you think of any factors that can explain any discrepancies you find?

- Plot your data for the lower current setting on the same plot and in the same units. Once you know the lamp temperature at one current setting, there are a couple different methods you can use to try to determine the temperature at the other setting. One is to again look at the peak wavelength and use Wien's Displacement Law. A second is to note that the total power dissipated by the lamp is given by  $P = VI$ . Since the total power radiated is given by the Stefan-Boltzmann Law, you can estimate the temperature ratio from the ratio of the powers

dissipated with the two current settings. Finally, the resistivity of tungsten exhibits simple power law behavior between  $T = 293^\circ\text{C}$  and  $3000^\circ\text{C}$  (see graph); therefore, the change of resistance of the lamp can be used to measure its temperature change. The resistance  $R = \rho\ell/A$ , where  $\ell$  is filament length,  $A$  is filament cross-sectional area and  $\rho$  is resistivity. Since  $\ell$  and  $A$  are constants, we have

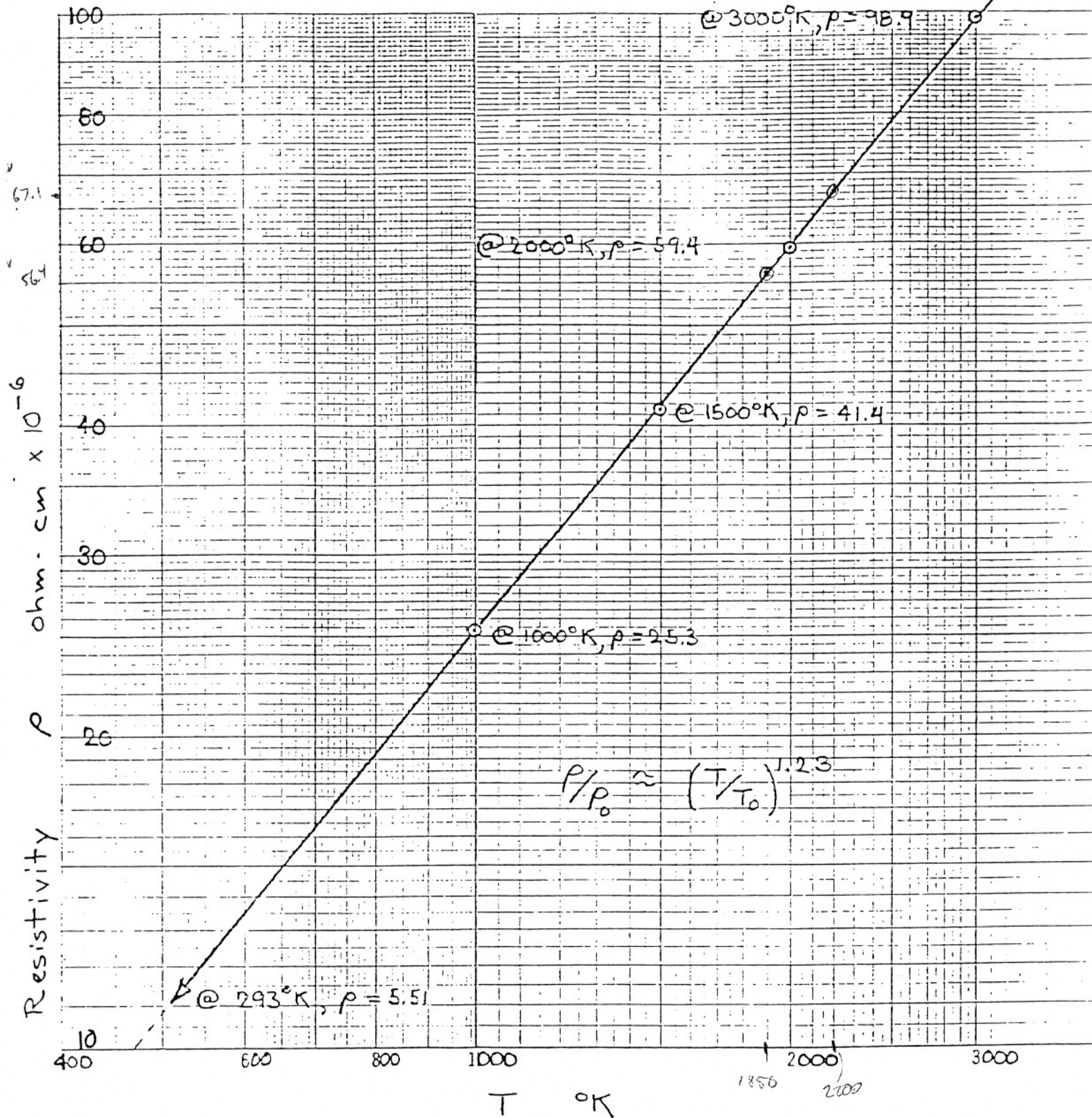
$$\frac{R(T)}{R(T_0)} = \frac{\rho(T)}{\rho(T_0)} = \left(\frac{T}{T_0}\right)^{1.23}$$

Thus by measuring the resistance at the higher and lower current settings, you can predict the temperature ratios. The experimental resistance  $R$  of the lamp is  $R = V/I$  (meter readings).

7. Plot the theoretical spectrum for the lamp using each of the three estimates of the temperature corresponding to the lower lamp current. How do each of these theoretical curves compare to your experimental spectrum in terms of peak wavelength, overall (integrated) intensity, and shape of the curve? Which method of estimating the lamp temperature appears to be the best.

Resistivity  $\rho$  vs. Temperature  $T$   
 for Tungsten  
 (HB of Chem. & Phys. - Langmuir 1916)

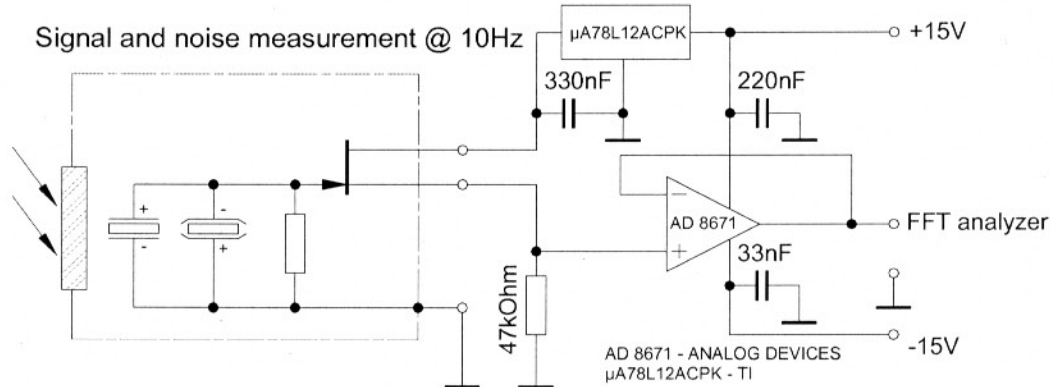
@ 3500°K,  $\rho = 118$



## LIE-316-#

2.0 x 2.0 mm<sup>2</sup> pyroelectric IR detector  
thermal compensated, JFET

## Test circuit:



## Parameters:

Element size / type	nom	2.0x2.0 mm <sup>2</sup> lithium-tantalate with black layer
Aperture	nom	5.0 mm sq.
Thermal time constant	typ	150 ms
Electrical time constant	typ	4 s
Polarity	nom	positive signal by positive IR flux change
Voltage responsivity {500K, 10Hz, 25°C, without window}	min	150 V/W
Noise density {10Hz, BW 1Hz, 25°C}	max	130 nV/Hz <sup>1/2</sup>
Detectivity {500K, 10Hz, 1Hz, 25°C, without window}	min	2.3*10 <sup>8</sup> cmHz <sup>1/2</sup> /W
Offset voltage {I <sub>Dopt.</sub> = 10-100μA}	nom	0.4 ... 1.5 V
U <sub>DS</sub>	max	18 V
Operating / Storage temperature	nom	-25 ... +85°C
Window cap		All InfraTec windows and filters are available (except KBr and CsI). Customized filters upon request.

InfraTec reserves the right to change these specifications at any time without notification!  
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<http://www.InfraTec.de>

represented by:

**InfraTec infrared LLC**  
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**Atlanta, GA 30318, USA**

Tel: 877-pyros4u  
Fax: 877-389-2668  
E-Mail: [sensor@InfraTec.de](mailto:sensor@InfraTec.de)  
<http://www.InfraTec.de>

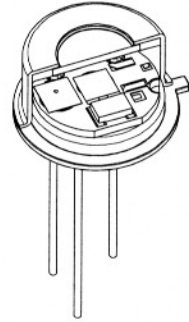
**LIE-316-#**

2.0 x 2.0 mm<sup>2</sup> pyroelectric IR detector  
thermal compensated, JFET

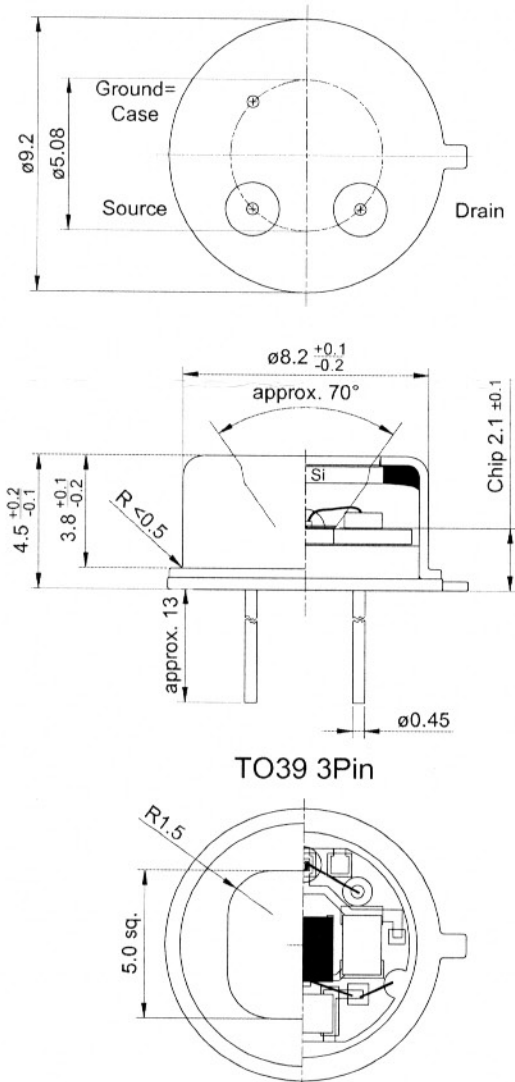
Description: LIE-316-#

[# = extension code]

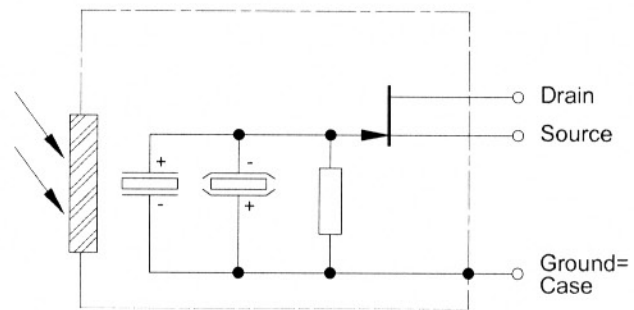
single element, area 2.0x2.0mm<sup>2</sup>, thermal compensation; for voltage mode



Housing:



Pin assignment:



Standard Products

**InfraTec GmbH**  
Infrarotsensorik und Messtechnik  
Gostritzer Straße 61–63  
**01217 Dresden / Germany**  
E-Mail: [sensor@InfraTec.de](mailto:sensor@InfraTec.de)  
<http://www.InfraTec.de>

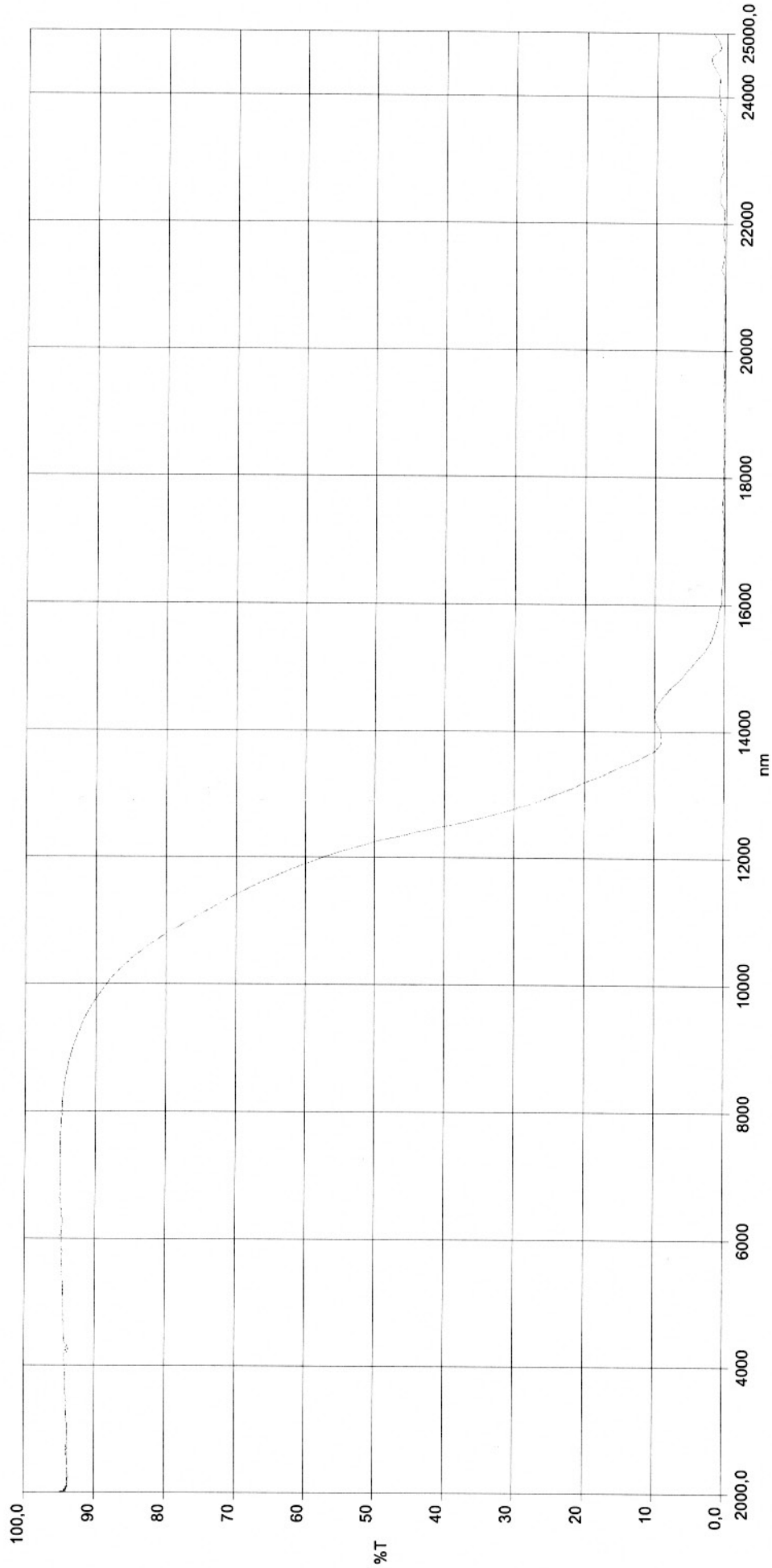
represented by:

**InfraTec infrared LLC**  
530 Means Street, Suite 120  
**Atlanta, GA 30318, USA**  
Tel: 877-pyros4u  
Fax: 877-389-2668  
E-Mail: [sensor@InfraTec.de](mailto:sensor@InfraTec.de)  
<http://www.InfraTec.de>

# Transmission

Description: CaF2 0,4mm thick

Date: 27.03.02  
Time: 13:48:23



Spectrum Pathname: r:\sensor~1\ir\_spe~1\sp\caF2\_04.sp  
Date Created: Wed Mar 27 13:11:42 2002  
Data Type: PE IR SPECTRUM  
Accumulations: 50  
Resolution: 4.00 cm-1

Analyst: InfraTec GmbH