Hot Electron Thermal Emission Spectroscopy

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Available at www.github.com/leoole100/projekt-praktikum.

1 Introduction

2 Experimental Setup

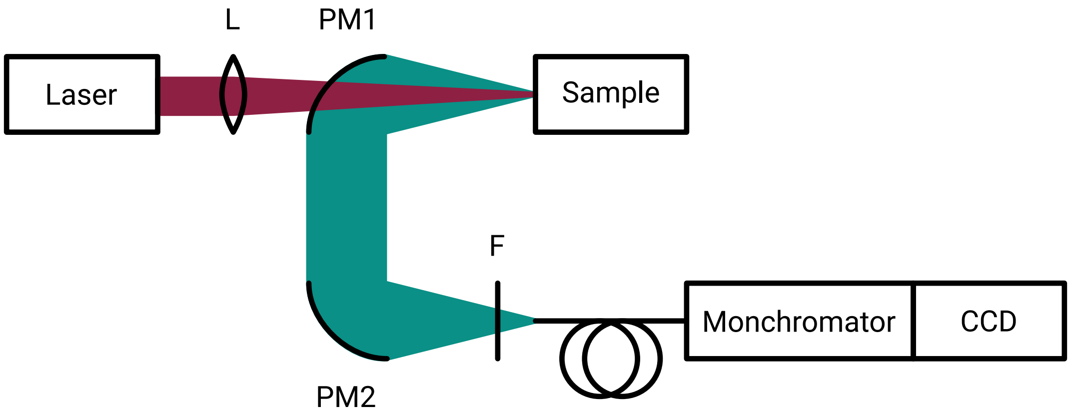

Figure 1 Schematic of the experimental setup.

The experimental setup, as designed by Leon Roob [1], is show schematically in Figure 1. It is a broad-band photoemission setup.

Firstly the laser is a Pharos **TODO** by Light Conversion with a wavelength of 1030 nm, a FWHM Pulse width of 250 fs and a repetition rate of 100 kHz. The beam is 4 axis stabilized and has a diameter of **TODO** mm, when it enters the experiment. The lens L with a focal length of 150 mm focuses the light on the sample with a diffraction limited spot size of $4\lambda f/\pi D =$ **TODO**.

The sample is absorbing the laser pulse and emitting thermal radiation into the half sphere. To collect and focus the broad band emission off-axis parabolic mirrors with UV-enhanced aluminum coating are used (PM). PM1 with a focal length of 50 mm is used to collect the emission and PM2 with a focal length of 101 mm is used to focus the light through a filter onto a bare multi-mode fiber end.

The used fiber is a QP200-2-SR-BX from Ocean Optics. A 200 µm multi-mode fiber for transmission from $300 - 1100$ nm.

To analyse the light a Acton SpectraPro 300i monochromator with a 150 lines/mm grating with a blazing wavelength of 500 nm is used. The light is detected using a Andor iXon^{EM}+ 897 EMCCD camera used in Vertical Binning mode as a line detector.

The lens L, the sample and the fiber end are mounted on 3 axis translation stages, to aid in focusing. The parabolic mirrors are fixed.

3 Characterization of Noise Sources

To be able to detect a the faint thermal radiation from the hot electrons it is necessary to optimize the signal-to-noise ratio (SNR) of the experiment.

The noise sources of the setup are mainly from the detector. Variation in the laser output power are assumed to be comparatively small and ignored in the following discussion.

The detector used is a EMCCD camera as is common for spectroscopy. The manufacturer Andor has some documents that discuss the Optimisation of SNR [2, 3].

The simplest noise source is *Readout Noise*. Every bin that is read out get's a constant noise from the CCD shifting and the analog to digital converter. For the high performance CCD camera used here this is in the order of $1\,e^-$ [4]. It is measured to be in that range in Figure 2. This is applied per read out bin, not per pixel, leading to the use of hardware vertical binning.

Another noise source is *dark current noise*. It is a results from thermal energy stochastically exciting electrons in the semiconductor of the detector. The noise this generates scales with temperature and time $N_{\text{dark}} \propto \exp(-E/kT) \cdot t_{\text{exp}}$. This is shown in Figure 2. For this reason scientific cameras are mostly cooled, here to $-80\,^{\circ}\mathrm{C}$, such that this is insignificant for this setup.

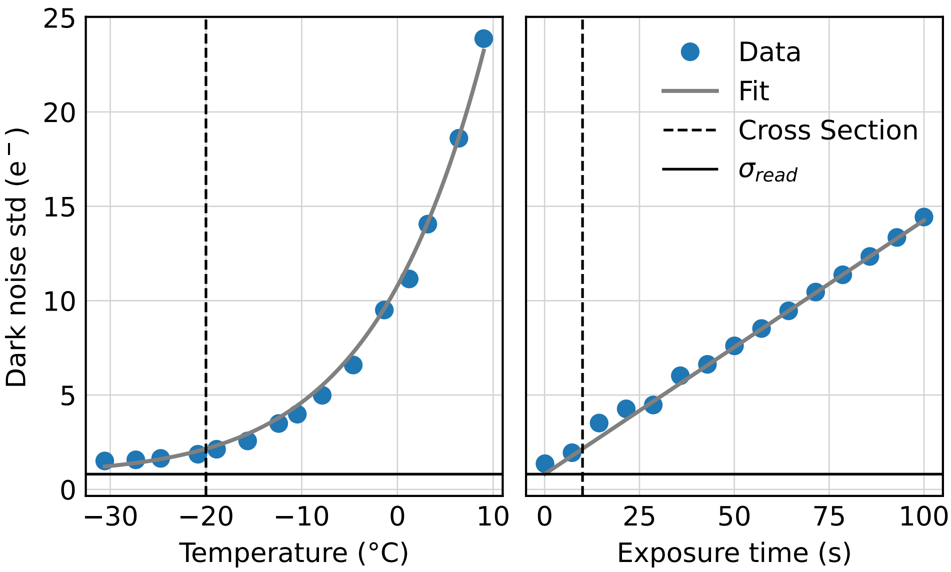

Figure 2 Dark noise as a function of sensor temperature and exposure time. The curve is fitted with an effective activation energy of $E = 0.597(4)\,\mathrm{eV}$ and a constant readout noise of $\sigma_{\text{read}} = 0.81(12)\,e^-$.

Then there is is *Clock Induced Charge Noise*, that scales with the electron multiplying gain in the detector. For this reason it is beneficial to deactivate the sensor gain, when the signal is about 42 times stronger that the readout noise [2].

The main resulting noise source is shot noise, such that the system is called shot noise limited. **TODO**: It is still to be researched if the shot noise is per photon, or per electron.

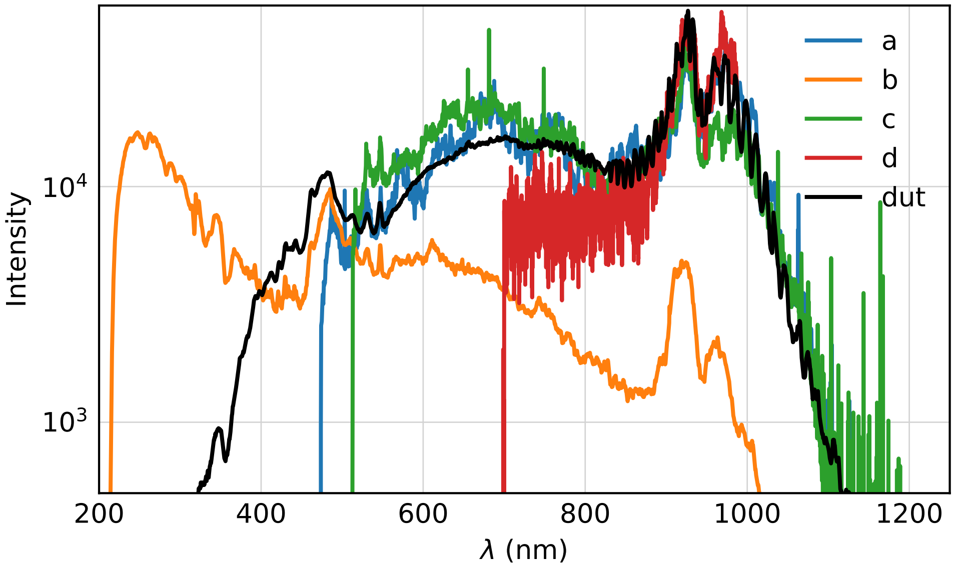

Figure 3 Same spectrum recorded with different instruments.

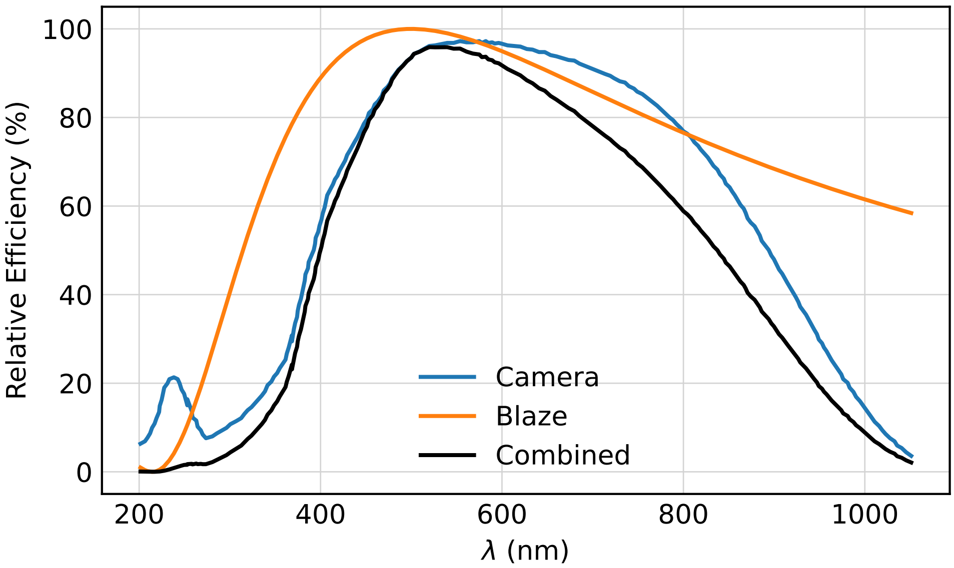

Figure 4 Transmission curves of various components and filters used in the setup.

4 Efficiency and Flatness

4.1 Calibration

5 Data Analysis and Spectral Modeling

6 Conclusion

References

[1] Leon Roob. “Thermal Radiation from Ultrafast Hot Electrons in Graphite”. en. Universität Konstanz, Apr. 2025.

[2] Andor. *Establishing Sensitivity in Scientific Cameras*.

[3] Dr. Jo Walters. *Sensitivity and Noise of CCD, EMCCD and sCMOS Sensors*. Apr. 2023.

[4] Andor. *iXonEM+ 897*.