Low Energy Electron Difraction (LEED)

1. Introduction

In this experiment we use low energetic electrons with an energy of 50-500eV to examine surfaces. The depth of penetration of low energetic electrons is limited to a few lattice planes. Therefore, this method is surface sensitive. LEED allows to image a crystal surface by reflection of the electron beam.

The first electron scattering experiments were done by Davisson and Germer in 1927. These experiments were a clear proof of the electronic wave nature[1]. Figure 1 shows a typical experimental setup that is used to obtain the image of scattered electrons.

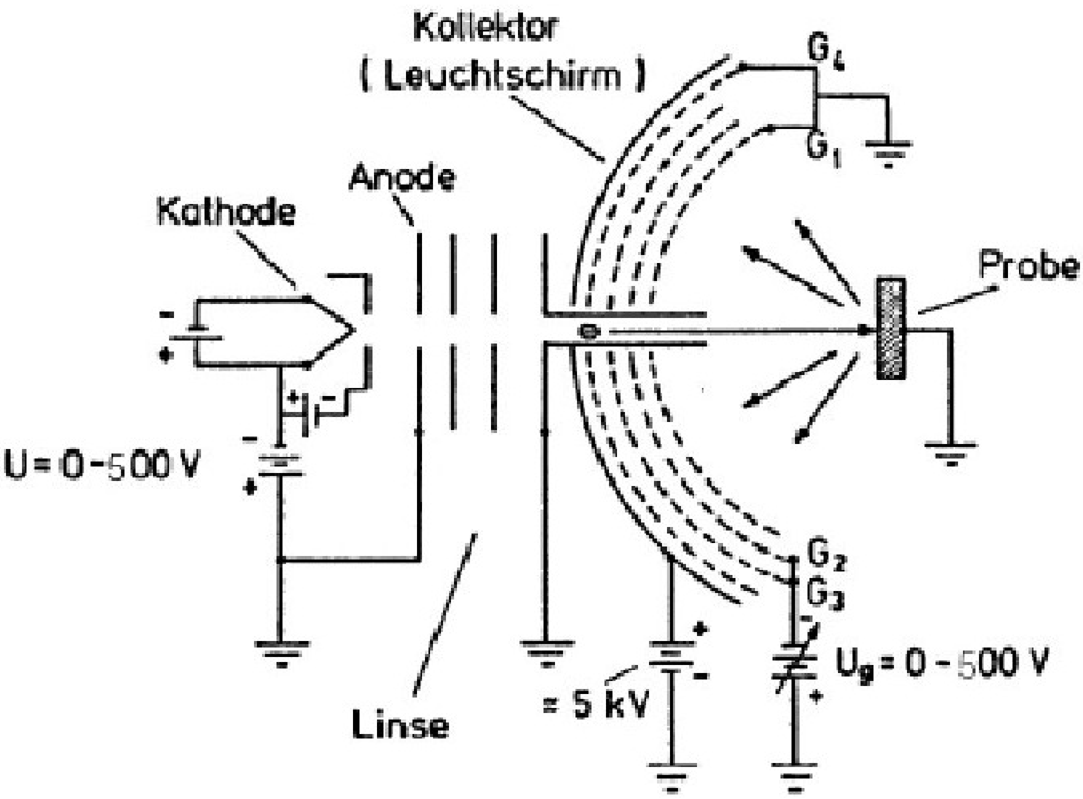

Fig. 1: Draft of a LEED optic. The optic of the current experiment can be seen on the webpage of Omicron[2]

The LEED technique is a standard method in surface physics. LEED instruments are part of many high vacuum setups.

2. Experimental Setup

The LEED experiment requires an ultra high vacuum environment (p~10^{-10} mbar). Under ambient conditions the surface of the sample is contaminated by all kinds of molecules and atoms within a short period of time[2]. To assure a clear surface the setup is equipped with a standard set of vacuum pumps[3,4]:

1. **Rotary vane pump**
2. **Turbomolecular pump**
3. **Ion getter pump**
4. **Titan sublimation pump**

The pressure within the chamber can be monitored by a **ionization manometer**. The surface of the sample can be cleaned using a sputter gun. This device accelerates ionized Ar-atoms with a field of 2000V. These ions are focused by electrostatic lenses. Atoms and molecules that adsorb to the surface are removed by the ion beam. However, the surface remains rough after the sputtering process. By heating up the sample the surface can rearrange and a clean and smooth surface can be obtained. This process is called tempering.

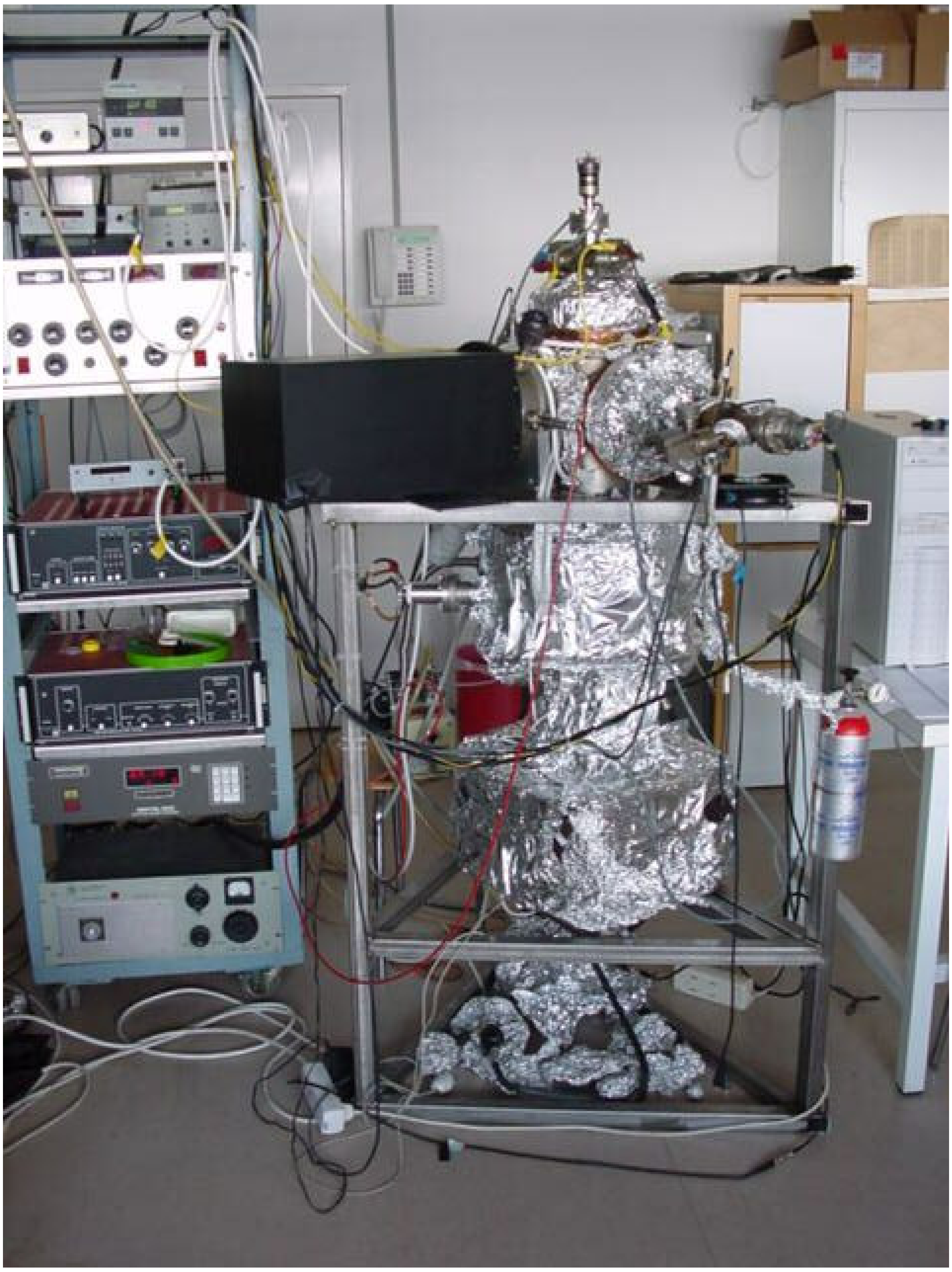

Fig.2: Photograph of the chamber used in the experiment

The procedure of sputtering and tempering a sample is a standard technique in surface science. Please refer to the overview of cleaning techniques by Musket et al.[5]

In the present experiment we use a Cu(100) surface. The surface is cleaned by the sputter gun and heated up to 450°C.

The scattered electrons are detected by a fluorescence screen and a CCD camera. The images are processed by computer software. The LEED system can be controlled by the software. This allows to take an **I(V)-curve**.

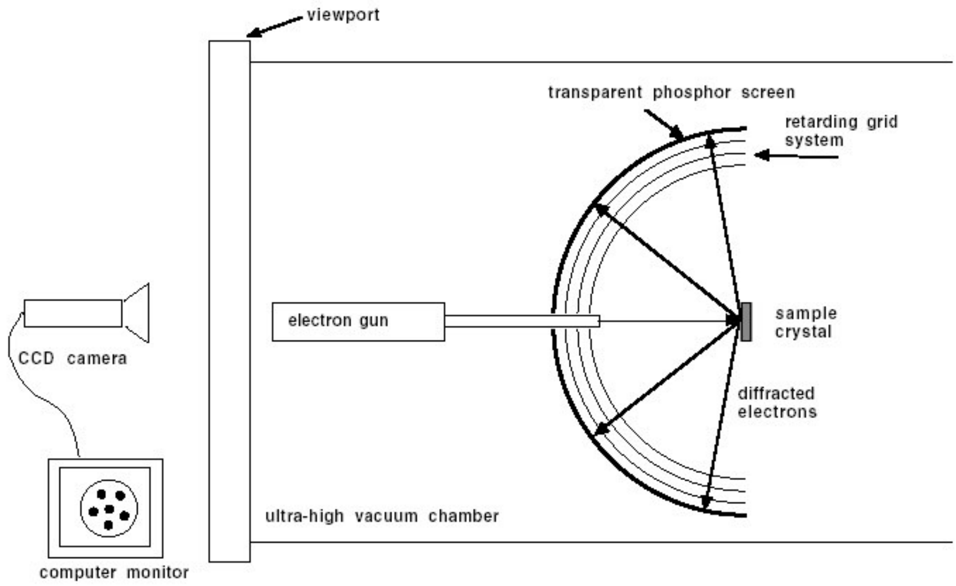

Fig.3: Draft of the LEED system, CCD camera and computer

3. What you are supposed to know and to learn:

In order to understand the scattering process, please recall the aspects of scattering at a grating. How is the resolution limit of a grating spectrograph defined?

Usually, LEED technique is used to determine the surface structure of a sample. You can find out more about the surfaces of different crystal structures on the webpage of the Fritz-Haber-Institut[6].

At an electron energy of 20-500keV the **de Broglie wavelength** is on the same scale as the atomic distances. At perpendicular incidence of the electron beam the connection between the **reciprocal lattice** and the image is easy to understand. The image on the screen is a proportional projection of the **Ewald sphere**. Thus, the image on the screen shows a to scale image of the **reciprocal space**.

In the real experiment the wave vector of the incident beam is undetermined up to a certain point. The impact of this effect can be described by the **coherence** of the incident beam.

Due to **chemisorptions** the sample surface can be covered by a **superstructure**.

4. The experiment

To obtain vacuum conditions we use the vacuum pumps as stated above. You have to produce a clean surface by sputtering and tempering the sample. By leading oxygen into the chamber you can produce a superstructure.

5. Problems (Problems 5.1-5.6 have to be solved in advance)

5.1 Calculate the wavelength of monochromatic electrons which are accelerated by a voltage V_0. What is the relativistic correction for V_0=500eV? Estimate the energy at which it is necessary to use a relativistic correction?

5.2 Determine the condition for constructive interference in a scattering event. How does the usage of the reciprocal lattice leads to the same result?

5.3 Imagine a plane wave λ which hits a two dimensional quadratic lattice (lattice vectors $\vec{a}_1, \vec{a}_2$ with $|\vec{a}_1| = |\vec{a}_2| = a$, Fig. 4). The wave is scattered at the lattice. Validate the condition

$$\sin\theta_{n,m} = \frac{\lambda}{a}(n^2 + m^2)^{1/2}$$

for $\theta_{n,m}$ (n,m integers). Comment on the effect of n and m. (Hint: Consider the projection of the sinus).

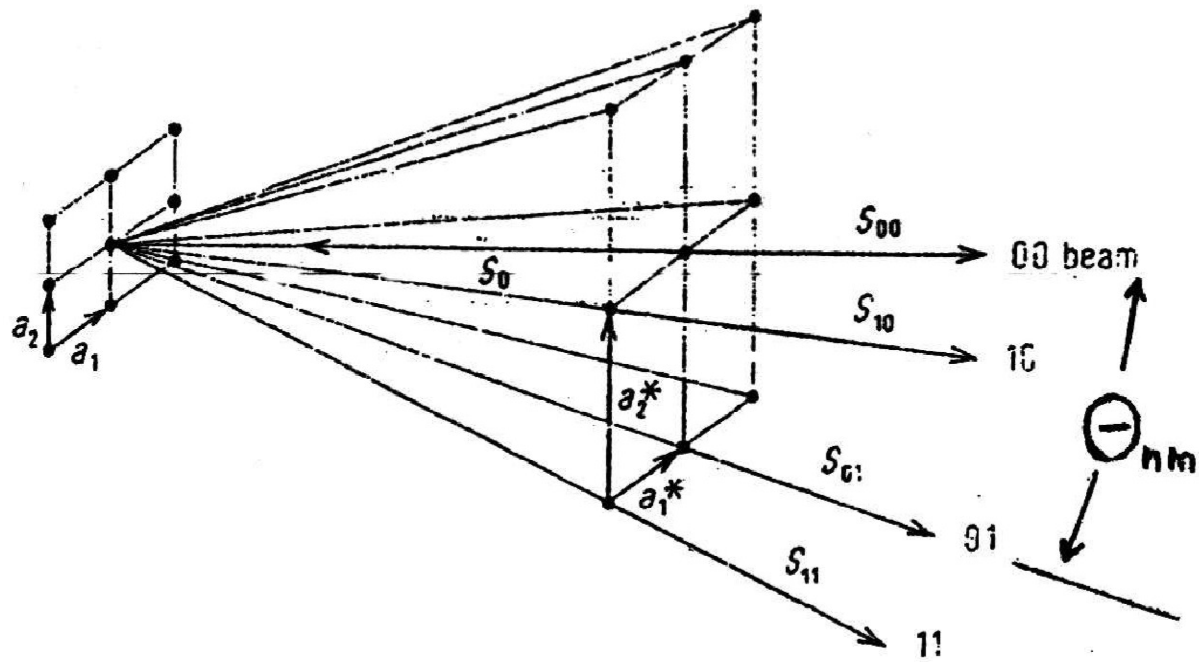

Fig.4: Draft for problem 5.3 and 5.4

5.4 Application of LEED: S_0 is the direction of the incident electron beam (Fig. 4). The wavelength is $\lambda(\text{Å}) = \frac{12.26}{\sqrt{V(eV)}}$, where V is the energy of the electrons. Calculate the minimum energy V_0 for a lattice $a = 2.55\text{Å}$ (Cu-Cu-distance) such that
a) the first order reflex m=n=1 and m=0, n=1 and
b) the second order reflex m=n=2

hit the sphere with an opening angle of 52°. Make a draft of the scattered image.

5.5 Make a draft of an $(\sqrt{2}\times 2\sqrt{2})R45°$ superstructure on a Cu(100) surface. The superstructure is written in the **Woods notation**. The rules of the Woods notation are explained in Chap. 9 (page 215) of Ertl-Küppers textbook[3].

5.6 Discuss the **kinematic approximation**. Show how the perpendicular lattice constant can be calculated from the **I(V)-curve** of the **(0,0) beam** using the kinematic approximation.

5.7 Make a clean Cu(100)-surface by using the sputtering and tempering technique. Take LEED spectra of the clean surface at energies between 50 and 150eV. Determine the lattice constant by using the results from 5.1-5.3.

5.8 Take a I(V)-curve of the (0,0)-beam in the energy range 200-600eV. Determine the lattice plane distance. Hint: The Ertl-Küppers textbook shows an I(V)-curve of Ni(100). This might be useful to determine the scattering order.

5.9 Use the dosing valve to lead oxygen into the chamber. Using the correct parameters leads to an oxygen superstructure on the Cu surface. Take LEED pictures of the superstructure at an energy range of 50-150eV. Compare the pictures to those from 5.7 and compare the results. You should be able to clearly see the superstructure. Characterize the superstructure by the means of the Woods notation. Is the result in agreement with 5.5?

6. Literature

[1] www.nobel.se/physics/laureates/1937/davisson-lecture.pdf
[2] www.omicron.de/pic/specta.jpg
[3] M. Henzler und W. Göpel, Oberflächenphysik des Festkörpers Kap.2, Teubner Studienbücher Physik, Stuttgart. 1991
Low Energy Electrons and Surface Chemistry,
G. Ertl, J. Küppers, Kapitel 9, VCH, Weinheim, 1985.
[4] http://www.cem.msu.edu/%7Ecem924sg/Topic02.pdf
[5] R.G. Musket et al. Applications of Surface Science 10, 143 (1982)
[6] www.fhi-berlin.mpg.de/~rammer/surfexp_prod/SXinput.html