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Description and Performance of an EELS Spectrometer

1. Introduction

In the recent years, electron energy loss spectroscopy (EELS) has proved to be a powerful technique in studying vibrational and electronic excitations in solid state [1,2]. In particular, high resolution spectrometers using low energy electron beam, thus sampling only a few atomic layers, have become an important equipment in laboratories engaged in surface studies. In our laboratory, the electron energy loss spectrometer based on a tandem monochromator – analyzer, has been constructed. The purpose of this paper is to present its design and performance. The latter is shown an the basis of electron energy loss spectra for the Si (111) surface at the primary electron beam energies 82 eV, 102 eV, 122 eV.

2. Apparatus

a) The tandem monochromator – analyzer

The heart of the spectrometer (Fig. 1) is the tandem monochromator – analyzer based on two electrostatic deflection cylindrical condensors 127°. The pass energy of an electron beam transmitted by the cylindrical condensor of deflection angle 127° is determined by the potential difference ΔV between its electrodes. The relation giving E_o is obtained from the condition of dynamical equilibrium on the circular path for an electron with that energy, and it is written

$$E_o = e \cdot \Delta V / 2\ln\frac{r_o}{r_i} \quad . \tag{1}$$

where ΔV is the potential difference between the electrodes and r_o , r_i are the radii of the outher and inner electrode, respectively. In addition to the pass energy E_o, the trans-

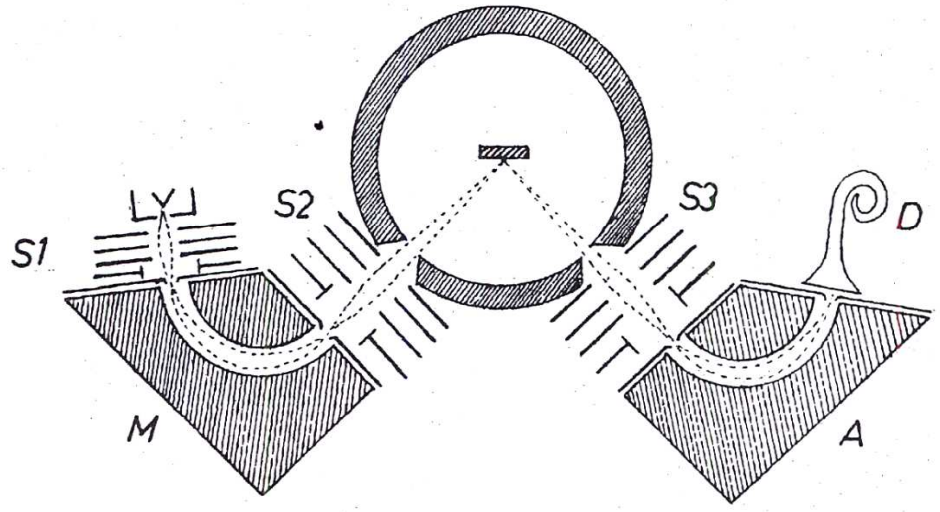

Fig. 1. Schematic diagram of the spectrometer for the electron energy loss measurement (M — monochromator, A — analyzer, S1, S2, S3 — electrostatic lenses, D — channeltron).

mission window of the analyzer must be introduced. It is determined as the halfwidth $\Delta E_{1/2}$ of the transmitted energy distribution around the pass energy E_o. According to Rudd[3] the resolving power $\Delta E_{1/2}/E_o$ of a 127° cylindrical analyzer can be estimated by

$$\frac{\Delta E_{1/2}}{E_o} = \frac{s}{R} + \frac{\alpha^2}{3} + \frac{\beta^2}{4} \tag{2}$$

with R being the mean radius of the analyzer, s being the width of the of the entrance slit, and α and β being semiangular divergencies of the beam in the radial and axial planes. From the formula it is evident that the resolving power is determined by geometrical factors and the absolute energy resolution $\Delta E_{1/2}$ is linearly dependent on the pass energy E_o. Thus it is convenient to work at low pass energy to get better resolution of the system. For the applied analyzers the geometrical factors were: R = 12.5 mm, s = 0.50 mm and the contribution from the beam divergency of the order of 0.02.

Another factor, which has influence on the performance of an electrostatic analyser, is a method of supplying voltage to its electrodes. The best is such a way, that the central path has a zero potential with respect to the entrance slit and the potential difference ΔV is applied symmetrically $(-\frac{1}{2}\Delta V, +\frac{1}{2}\Delta V)$ to the electrodes. This method was used in the monochromator (M), where for a given beam energy, the potential difference ΔV is constant. In the condensor working as the analyzer (A), it is necessery to sweep spectrum by changing the potential difference ΔV. This was performed by varying only the potential of the inner electrode, keeping that of the outher electrode constant. This method has the inconvenience that the asymetrical scanning of ΔV changes the potential of the entral path and therefore modifies the energy of electrons which enter the analyser. However, this method, as simple and rapidly applicable, was applied in the analyzer (A).

b) The electron gun and electrostatic lenses

The electron gun is essentially formed of the three parts: the electron source, electrostatic lens S1 and deflection electrodes. The purpose of the lens S1 is to focus the emitting tip of the filament into the entrance slit of the monochromator. The lense S2 focuses transmitted beam into the slit in a scattering chamber. The scattering chamber is a cylindrical closed cell on the potential of a sample, in order to avoid broadening of the electron energy distribution. Slits in the scattering chamber (0.07 mm) are located at the angle 90°with the aim to measure the electron spectrum in specular direction at the incident angle 45°. The lense S3 allows to focus reflected electrons into the entrance slit of the analyser. The spectrometer is enclosed in a high vacuum evacuated by absorption pumps and the titanium sublimation pump. The ultimate vacuum is of the order of 10^{-8} Torr.

c) The detection and data acquisition system

Since scattered electron currents are low, the detector used is an electron multiplier (channeltron) working in the pulse counting mode. The delivered pulses are injected into a preamplifier and then amplified, discriminated and shaped. The counting rate is registered by the IBM computer in a given interval of linearly changing sweeping voltage at the rate about 0.04 V/s.

3. System performance

a) EELS spectra

The obtained spectra at incident beam energy 122 eV, 102 eV and 82 eV are shown in Fig. 2. The energy scale presents the energy loss δE determined as $\delta E = E_o - E$, with E_o being the energy position of the elastic peak. The abcissa gives the value of experimental cross section S_{exp}. It is defined as

$$S_{\mathrm{exp}} = \frac{I_{inel}(E)}{\int I_{el}\, dE} \tag{3}$$

where $I_{inel}(E)$ denotes the count rate in the inelastic channel and $\int I_{inel}\, dE$ is the integral over the elastic peak. The count rate in the elastic peak changed from the order 10^4 s^{-1} peak at the 122 eV to the order 10^3 s^{-1} at 82 eV. One can observe a significant difference in inelastic part of the spectra. At incident energy above 100 eV, inelastic electrons from a broad hump around the energy loss about 20 eV with a similar value of a cross section. The spectrum at 82 eV is qualitatively different. Its inelastic part is centered near the energy loss about 12 eV. It is known that in the energy loss spectra for Si the dominant features are plasmon excitations with energy losses 17 eV for the volume plasmon and 11 eV for the surface plasmon [4]. From the obtained spectra we may state that below the incident energy 100 eV probability of high ebergy volume excitations is significantly decreasing. Poor energy resolution of the system does not allow to distinguish partcular excitations although the spectrum at 82 eV shows some signs of a structure at the energy loss about 6 eV.

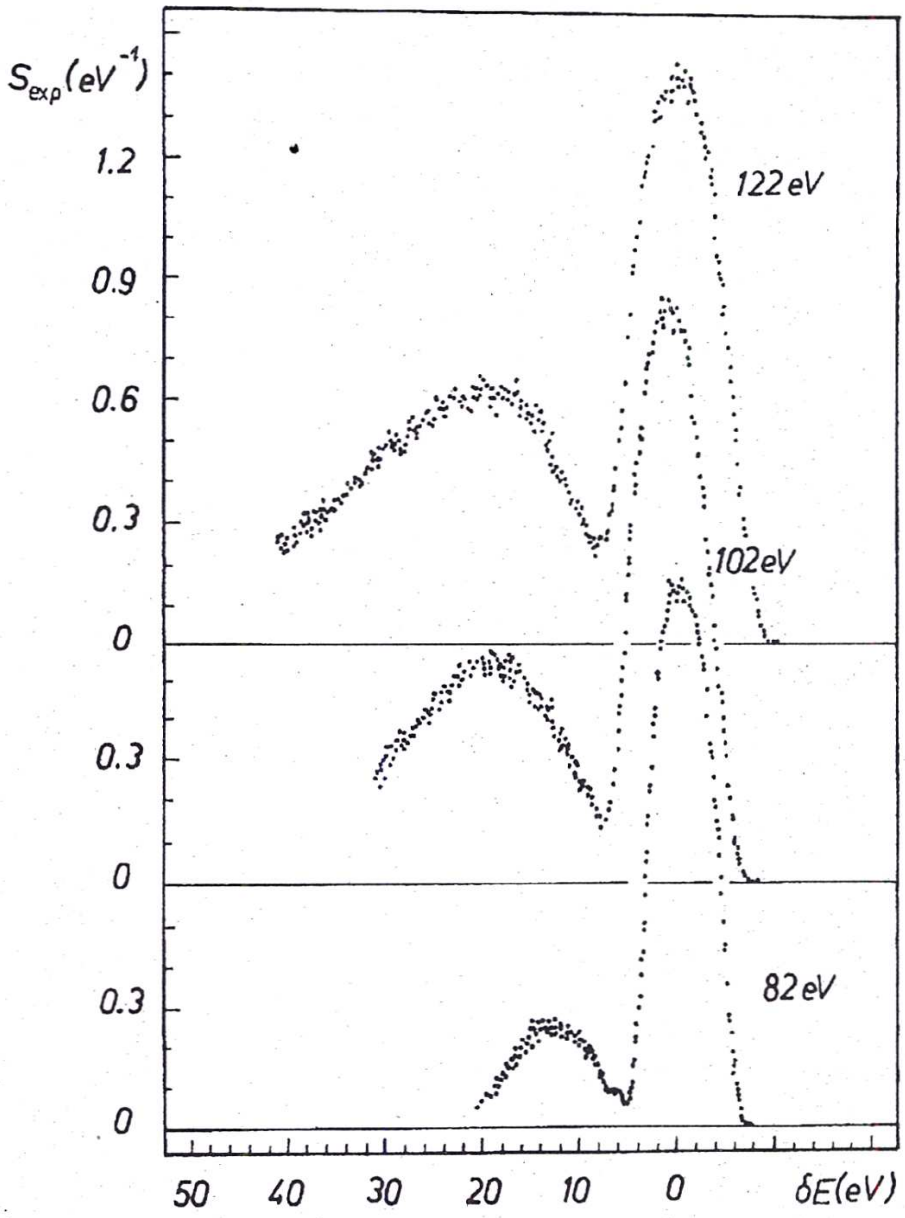

Fig. 2. Electron energy loss spectra on Si(111) at incident energies 82 eV, 102 eV, 122 eV in specular reflection at 45°

b) Energy resolution

The energy resolution of the spectrometer is experimentally determined as the energy halfwidth $\Delta E_{1/2}$ of the elastic peak. It is a convolution of energy resolutions in a monochromator $\Delta E_{1/2m}$ and analyser $\Delta E_{1/2a}$, thus

$$\Delta E_{1/2} = (\Delta E_{1/2m} + \Delta E_{1/2a})^{1/2} \tag{4}$$

As shown in eq. 2 it is linearly dependent on the primary electron beam energy E_o with the slope being the total resolving power. For the obtained spectra from a regresion analysis we get the total resolving power equal to 0.100 with the standard deviation 0.005. Taking into account a factor of 1.25 resulting from acceleration caused by asymetrical sweeping in the analyzer, we obtain the value 0.060 (± 0.007) for a resolving power in a single cylindrical deflector.

4. Conclusion

The EELS spectrometer described in this paper gives energy loss spectra on Si(111) which are in qualitative agreement with expectations. Its energy resolution however, is too poor to distinguish particular low energy excitations. In order to improve its resolution, the pass energy shoul be lowered both in the monochromator and analyzer.

References

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