LEED Intensity Measurement by Photographic Method with Digital Image Processing

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An accurate photographic method for measuring intensities on a fluorescent screen is described. Simultaneously with the fluorescent screen a calibrated 7-step grey scale is recorded on the film. Using a scanning photometer the intensity distribution can be digitized and by comparison with the grey scale converted to electron current density. As an example LEED-intensities from a Si (111)-surface obtained with the photographic technique are compared with spot-photometer measurements.

I. Introduction

Accurate measurements of LEED intensities are usually done by collecting directly the total electron current of a diffraction spot using a Faraday cup, or by measuring the brightness of the spot on the fluorescent screen using a spot photometer. These are laborious and time consuming processes. For the purpose of collecting a sufficiently large amount of data within a tolerable time, and particularly in the prospect of applying the averaging method, an easier and quicker method is desirable.

Recently new methods [1 – 3] have been reported allowing a rapid automatic recording of LEED intensities. Stair et al. [1] have used the photographic method combined with a rapid film-development apparatus and a digital photodensitometer. Heilman et al. [2] have used a computer controlled television system for digital recording of the pattern on the screen. This method allows an on-line processing of the diffraction pattern. A combination of the two methods – photographic recording and subsequent analysis by means of a television unit – was reported by Frost et al. [3].

In the present paper a photographic method combined with digital processing is reported. This method has been developed for application to the LEED analysis of the (2×1) structure of the silicon (111) surface [4]. The structure is metastable and requires a quick measurement of diffraction intensities. The power of the photographic method for this kind of cases has already been pointed out by Stair et al. [1]. The photographic method was preferred here due to its simplicity in taking records and the capability of storing permanently a much larger amount of data compared to digital storage. The difficulty in controlling the film-development process was circumvented by recording a seven step grey scale simultaneously with the LEED-pattern.

The digital processing of the obtained pictures was carried out applying an arrangement built originally for two-dimensional digital analysis of electron microscopic pictures. For our first purposes of evaluating integrated intesities of diffraction spots this arrangement was satisfactory without any change.

II. Photographic Recording of Diffraction Patterns

Figure 1 shows the schematic diagram of the experimental arrangement of photographic recording. In front of the window of the LEED chamber two small stripes of mirrors (M in Fig. 1) were attached on the both sides, so that on the left the 7-step grey scale and on the right an 8-digit display showing the relevant data of each LEED-pattern were visible at the both ends of the photographic frame. An example is shown in Figure 2.

The 7-step grey scale was made by exposing a stripe of film in 7 different areas, the exposure time

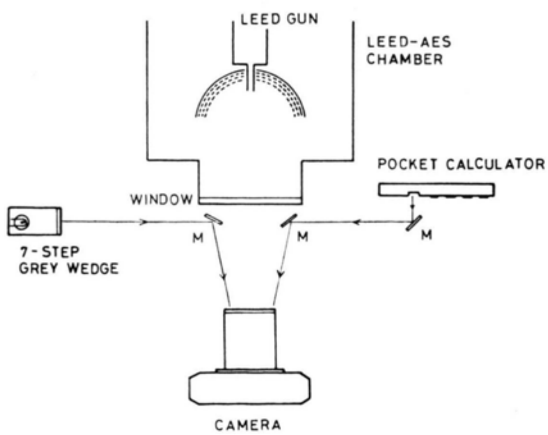

Fig. 1. Experimental arrangement for the calibrated photographic recording of LEED intensities. In the preliminary experiment the digital display of a pocket calculator was used.

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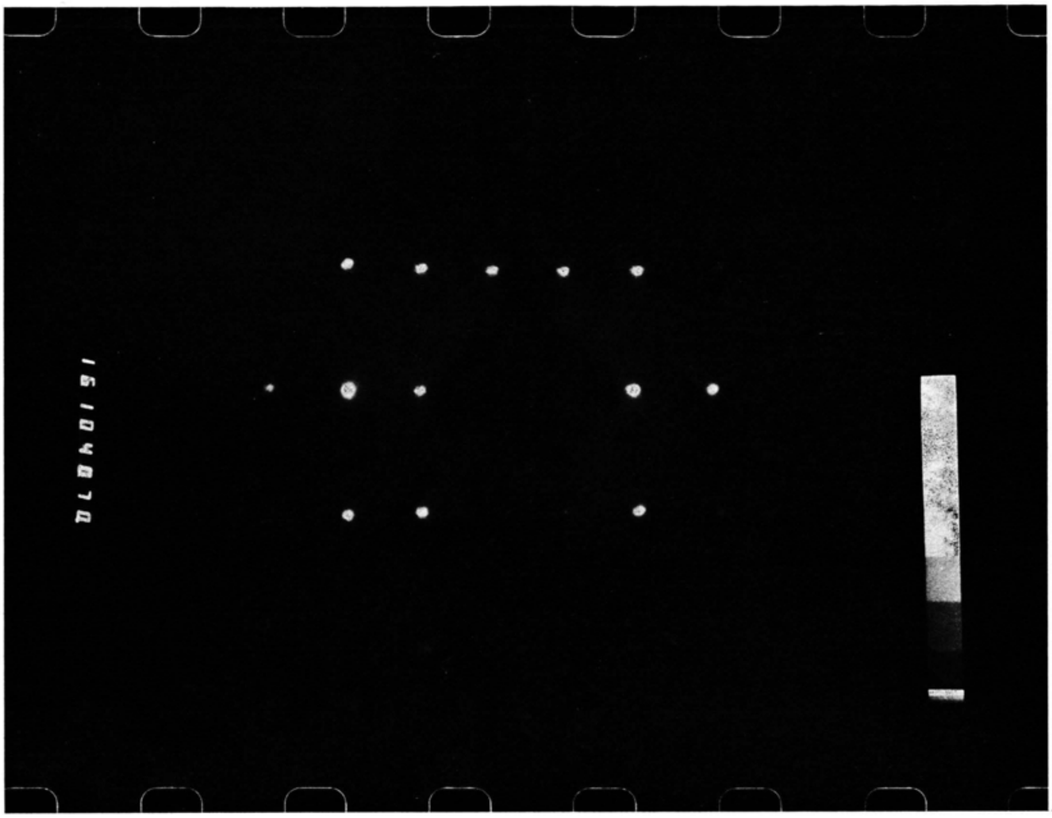

Fig. 2. Photograph of the recorded diffraction pattern with grey scale and digital display.

increasing in such a way that after development nearly equal darkness steps were obtained. As shown in Fig. 1 the scale was illuminated from behind by a fluorescent lamp. The illumination intensity was chosen so that the brightness range of the 7 steps covered roughly the wanted brightness range of the diffraction spots.

For calibrating the grey scale a spot photometer devised for the usual LEED use was set exactly at the position of the camera and the brightnesses of the 7 areas of the scale were measured. The used mirror reflex camera (MINOLTA MX-1 MOTOR) allowed to choose by hand long exposure times up to 16 seconds. The motor-driven film transport, and the remote electric contact shutter release made the camera automatically ready for the succeeding exposure within a fraction of a second. This was essential for an easy and quick recording of a large number of diffraction patterns.

The used film (ILFORD HP-4) had the sensitivity of ASA 400. Typical exposure times were 2 and 4 seconds for a camera aperture of 3.5. The film was developed in a normal developer (RODINAL 1 : 50). Any particularly restrictive condition for development was not necessary. This was an essential advantage gained by the simultaneous recording of the 7 step scale with each LEED-pattern.

III. Digital Photometry

For photometrizing the diffraction patterns and the grey scales recorded on the films a photometer (DIGISCAN) with a digitally controled x-y movement of the table was used. In the photometer the picture is moved continuously along a line under the objective of an optical microscope. The movement is controlled by a digitally driven table which can be programmed. The distance and number of sampling points can be chosen independently in the x and y directions. The measured transmitted radiation is converted into electrical signals by a special semiconductor detector. The electrical signals are indicated by a digital voltmeter and recorded on magnetic tape. The transmitted light intensity through the film I_t is proportional to the transparence $T = I_t/I_0$ where I_0 is the primary intensity.

The wanted diffraction spots (usually 10 to 15 in number) were searched out manually on the photometer table and only a small area of $0.5 \times 0.5\ mm^2$ including the intensity area of a diffraction spot was scanned automatically in 10×10 steps. Thus, the intensity profile of one spot was scanned in 100 small quadratic mesh areas.

Also the seven areas of the grey scale were photometrized. It was found that the development was satisfactorily uniform throughout the film so that only the grey scale of each 10th frame had to be photometrized for checking the calibration.

IV. Computer Processing

The data on the magnetic tape were processed on a large scale computer (DEC 10). A highly sophisticated testing program system was evaluated to guarantee a high reliability of the recorded data.

The first step of the analysis was the calibration of the spot intensities by the grey scale. It was found that for our purposes the spot-photometer readings of the brightnesses of the grey scale, called here "intensity" I, and the transparence T were the most useful quantities for calibration because the relation between this intensity I and the transparence T is approximately $\sim 1/T$. By a curve fitting procedure the 8 intensities (including zero) and 8 transparences (including the non-exposed background) could be interpolated satisfactorily by a formula

$$I = A/(T+B) + C\,T + D$$

using four constant parameters A, B, C and D. A typical curve is shown in Figure 3.

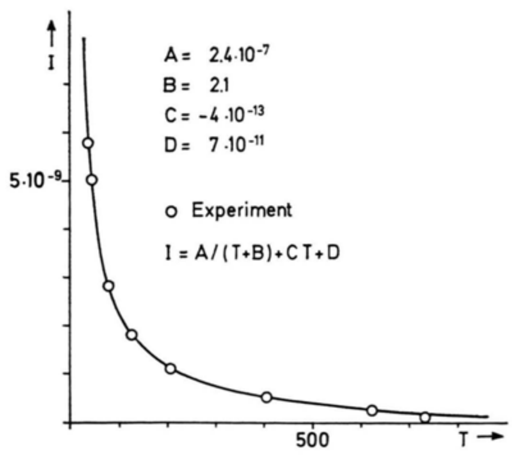

Fig. 3. Calibration curve of the film. Intensity of the grey scale versus the transparence of the photographic record (in arbitrary units). The open circles indicate the experimental measurements and the full curve was fitted to the experiment with the indicated set of parameters.

The computer program constructs the above calibration formula from the photometer readings of the grey scale (at every ten frames) and then the readings of diffraction spots are used to evaluate the sum of intensities over the 10×10 mesh areas as an integrated intensity of a diffraction spot.

As expected, a good agreement was obtained between the present results and the usual spot-photometer records of the diffraction intensity versus primary-electron energy curves. A few examples are shown in Figure 4. The deviations seen at a few places are not essential, because they are caused by the fact that some diffraction spots are partly masked by the specimen holder.

V. Discussion

The present intensity measurement is calibrated not directly to the electron beam intensity, but to the screen-brightness measured by the spot photometer. This is justified by the fact that the reliability of the spot photometer was proved by comparison with direct electron-beam intensity measurement using a Faraday cage [5].

The good agreement between the present results and the spot photometer measurements shows that at least in the present case there was no need of care about the difference in colour between the illuminated grey scale and the LEED screen, which would have caused different sensitivities for the spot photometer and the film.

The use of the 7-step grey scale was definitely advantageous to the use of a continuous grey wedge as in the case of Stair et al. [1]. The latter requires an extra exposure for the wedge and a very careful development of the film.

Compared to the direct television method [2] the present method has the advantage of having a very large permanent storage for the first record. Also the speed of recording may be higher, if one requires for television technique a good spacial resolution and a good signal to noise ratio.

The use of TV for the photometry [3] is obviously more convenient than the present kind of photodensitometry. The advantage of the use of the grey scale remains valid also in this case.

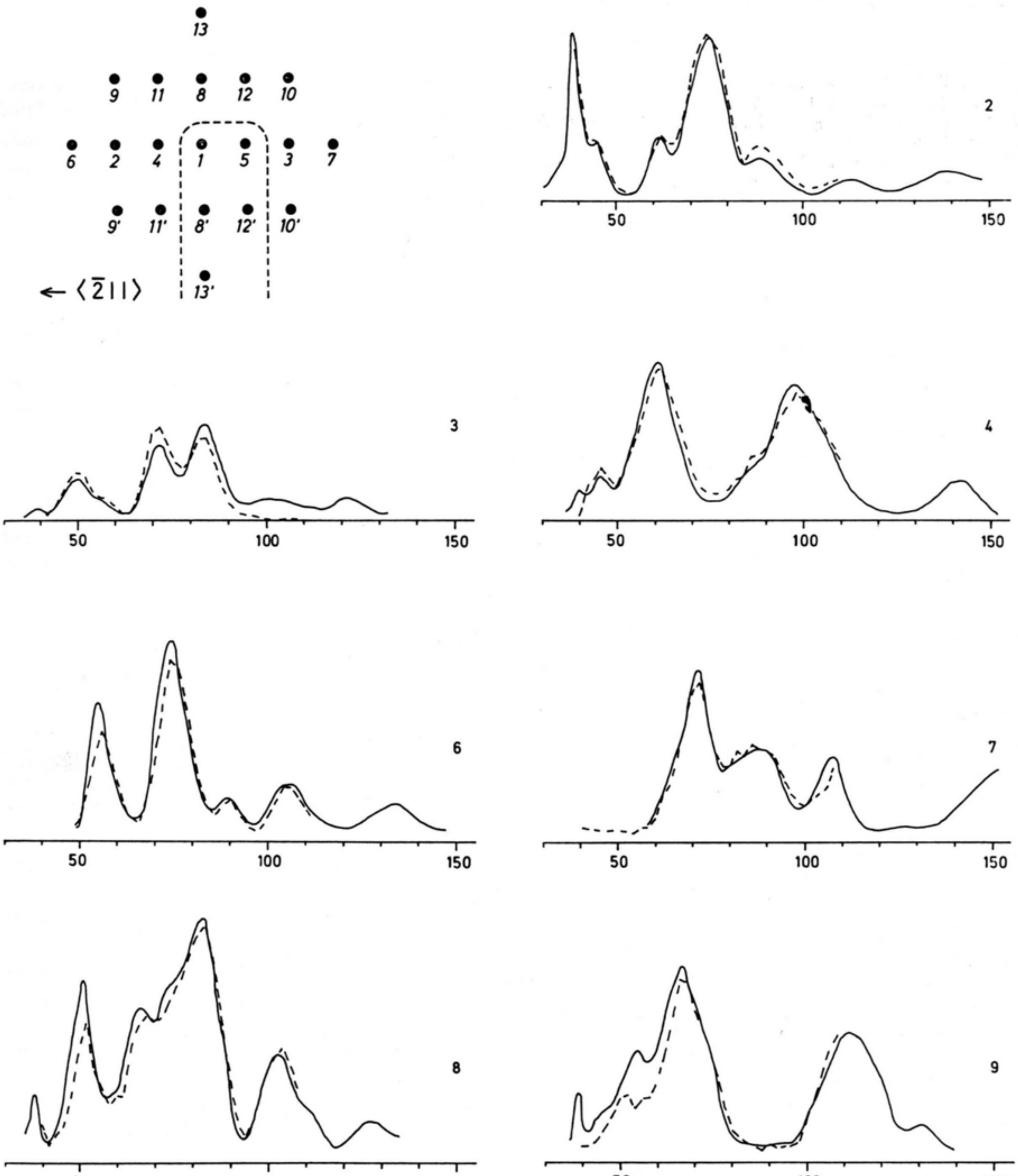

Fig. 4. Comparison of photographically determined intensities (dashed lines) with spot-photometer records (solid lines) of some LEED-reflections from a Silicon 111-cleavage face with the 2×1 superstructure [4]. The different diffraction spots are indicated in the schematic diffraction pattern. The intensity of the different reflections (in arbitrary units) is plotted versus the energy of the electrons in electron volts.

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