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Short note

Intensities of surface diffraction spots in plan view

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Values for the absolute intensities of surface diffraction spots in the plan-view geometry have been measured using an electron energy-loss spectrometer. The values are of the order of 10^{-4} relative to the incident beam, which is consistent with multislice calculations. Measurements of the spectra around the spots in on-zone and off-zone orientations indicate that (for silicon) the main background signal is due to plasmon scattering.

1. Introduction

The lessons of the past in electron microscopy indicate that theoretical modelling should go hand-in-hand with experimental analysis of images and diffraction patterns. With the development of microscopes around the world which can do electron microscopy in a UHV environment (see ref. [1] for a recent review), it is necessary to work on understanding the character of any results. One obvious question is the intensity of diffraction spots due to a surface layer. Experimentally, these diffraction spots are strong, often readily apparent on a phosphor screen, which might appear to be a little surprising. In addition, it is now established [2,3] that these spots are much clearer off the zone axis when the diffuse scattering around the bulk diffraction spots is attenuated.

The intention of this note is to report experimental measurements of the absolute value of surface diffraction spots using an electron energy loss spectrometer. We find that the values are of the order of 10^{-4} of the incident beam intensity, which is consistent with multislice calculations [4,5]. We also show that, at least for silicon, the primary component of the diffuse plume around the bulk spots is plasmon scattering.

2. Experimental method

The general method of sample preparation for surface studies was ion-beam cleaning/annealing and has been described elsewhere [3,6,7]. The sample used here was the Cu/Au on Si(111)5×5 surface, and details of the actual sample preparation will be described elsewhere [8]. Absolute intensity values were obtained using a Gatan parallel energy-loss spectrometer interfaced to an Apollo computer [9]. The procedure was, first, to determine the location of the spectrometer entrance aperture in terms of a position on the phosphor screen using the electronic "Image shift" unit on the microscope and maximizing the signal from the transmitted beam, and then use a dark-field tilt to bring the appropriate diffraction spot to the same position. The camera length of the diffraction pattern was chosen such that satellite spots can be discriminated from the main spots through the spectrometer entrance aperture. We have only used this approach for the stronger surface spots when they were visible on the screen.

3. Experimental results

Fig. 1 shows selected-area diffraction patterns of a 5×5 reconstruction on Si(111) due to a monolayer of Cu–Au alloy in (a) near (111) zone axis and in (b) off the zone axis (none of the (11) bulk spots were excited). There are two strong surface diffraction spots, namely the bulk forbidden {10} spots and the {4/5, 1} spots near the bulk {11} spots due to the 5 × 5 reconstruction. Representative electron energy-loss spectra are shown in fig. 2 from: (a) the transmitted beam near the zone axis (A in fig. 1a) ; (b) the (11) spot (B in fig. 1a), i.e. bulk (220) spot; (c) the (10) spot (C in fig. 1a); (d) the (4/5, 1) spot (D in fig. 1a)

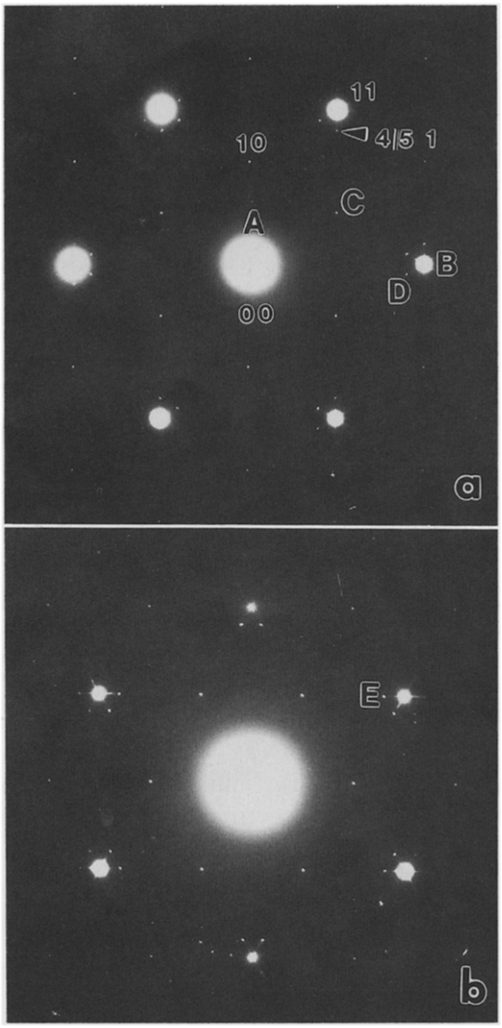

Fig. 1. Electron diffraction patterns of the Cu–Au on Si(111) 5×5 reconstruction: (a) near the zone axis and (b) off the zone axis.

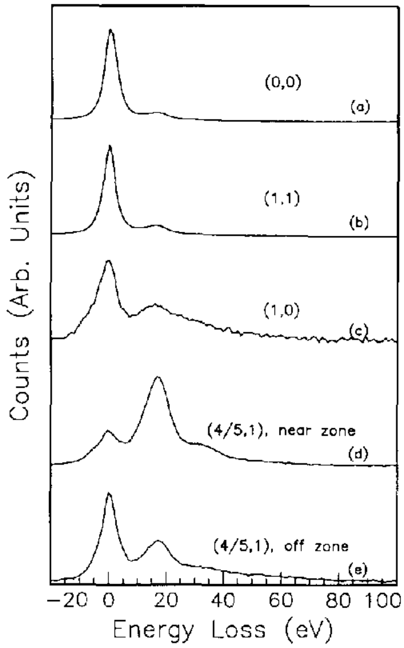

Fig. 2. Collection of PEELS spectra as described in the text.

and (e) the (4/5, 1) spot off the zone axis (E in fig. 1b). The intensity of the spectra is rescaled. The transmitted beam and the bulk (11) beam contain the same amount of plasmon loss intensity which increases with the specimen thickness (figs. 2a and 2b). Comparing spectra (d) and (e), it is apparent that near the zone axis there is a strong contribution from the diffuse plasmon scattering around the (11) beam which is confusing both the intensity level and clarity of the surface diffraction spots. However, when the specimen is tilted off the zone axis this plasmon scattering contribution drops since the intensity of the bulk (11) beam is reduced. The interpretation of these spectra is that the plasmon scattering near and under a diffracted beam is caused by the multiple scattering of both elastic (Bragg) and inelastic (plasmon) events [10].

Table 1 summarizes values of the intensities measured relative to the transmitted beam, integrating over the zero-loss peaks for both the near- and off-zone diffraction patterns. In the near-zone diffraction pattern, the intensities of the surface spots are found to be of the order of

Table 1
Intensities of different diffraction spots relative to the transmitted beam in the Si(111)5×5 diffraction patterns

Diffraction spot	Intensity (near the zone)	Intensity (off the zone)
(00)	1	1
(11)	3×10^{-1}	1×10^{-3}
(10)	5×10^{-5}	6×10^{-6}
(4/5, 1)	1×10^{-4}	2×10^{-5}

10^{-4}, which is consistent with our predictions from multislice simulations. In the off-zone diffraction pattern, the bulk (11) spot intensity dropped as much as two orders of magnitude while the intensities of the surface spots dropped by about one order of magnitude. (The two diffraction patterns were not from exactly the same area; therefore, we should be careful in comparing the absolute intensity levels. But the important information that we can draw is the intensity of the diffraction spots relative to the transmitted beam.) We should note that the error associated with our measurements is probably at most a factor of two. Better values could be obtained with a digital scan of the diffraction pattern into the spectrometer which we are in the process of implementing at present, but which will take some time to complete.

4. Conclusions

Absolute values of surface diffraction intensities were measured using an energy-loss spectrometer and appear to match well to what would be expected based upon multislice calculations. The visibility of the surface diffraction spots improves in an off-zone pattern compared to an on-zone pattern because of the attenuated bulk diffraction spot intensity and the associated diffuse plasmon scattering.

Acknowledgement

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