

(6) nachgewiesen. Bei Drücken zwischen 600 und 900 Torr im Sekundärstrahlrohr zeigen die gemessenen Geschwindigkeitsverteilungen Halbwertsbreiten, die nur sehr geringfügig über der Breite liegen, welche von der Durchlaßkurve des Selektors vorgegeben wird. Das bedeutet, daß die Halbwertsbreiten der Sekundärstrahl-Geschwindigkeitsverteilung kleiner als 7% sind, was Mach-Zahlen von $M > 25$ entspricht. Die gestreuten Primärstrahlteilchen werden in der Ebene, die durch die beiden Strahlen definiert wird, mit Hilfe eines Langmuir-Taylor-Detektors (5) nachgewiesen. Ein zweiter Detektor (7) dient als Monitor für den Primärstrahl. Die Verwendung zweier Monitordetektoren hat außerdem zur Folge, daß zeitliche Schwankungen in den Strahlen eliminiert werden können.

Um den Absolutwert der Relativgeschwindigkeit genau messen zu können, sind beide Geschwindigkeitsselektoren symmetrisch aufgebaut, d.h. die Relation zwischen Drehzahl und Sollgeschwindigkeit ist unabhängig von der Drehrichtung des Selektors. Durch Messung der Geschwindigkeitsverteilung mit beiden

Drehrichtungen können sowohl Justierfehler des Selektors als auch Justierfehler des Atomstrahls bezüglich der Selektorachse erkannt und korrigiert werden.

Abb. 2 zeigt ein Beispiel für eine Messung des differentiellen Streuquerschnittes. Aufgetragen ist $I(\vartheta) \sin \vartheta$ gegen den Winkel ϑ im Schwerpunktsystem. Man erkennt deutlich sechs sehr gut aufgelöste Regenbogenmaxima; man erkennt ferner die überlagerten Interferenzen kleinen Winkelfabstandes. Daß diese Interferenzen nicht so gut aufgelöst sind wie die Regenbogenextrema, liegt an der endlichen Winkelauflösung der Apparatur, die bei diesen ersten Experimenten aus Intensitätsgründen nur $0,45^\circ$ beträgt. Bei einem Winkelfabstand von $0,7$ bis $0,9^\circ$, der sich bei den Interferenzoszillationen ergibt, wirkt sich die Winkelauflösung natürlich stark auf die Interferenzen aus, während die Regenbogenstruktur hiervor praktisch unbeeinflusst bleibt.

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Influence of Bragg Reflection on Thermal Diffuse Scattering of Electrons in Si Single Crystals

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A variation of thermal diffuse scattering intensity is observed when the diffraction condition of the incident beam is varied. This indicates that the interaction potential between electrons and lattice vibrations is periodic within the crystal.

In two recent papers^{1,2} one of the authors has reported experiments on the influence of thermal lattice vibrations on anomalous absorption of electrons in Si and Ge crystals. It was shown that an increase of crystal temperature leads to an increase of the absorption parameters μ_0 and μ_h (see also³) and it was concluded that thermal diffuse scattering is one of the causes of anomalous absorption. Observations of diffraction contrast in energy selecting microscopes^{4–6} led to the same conclusion. This can be understood by the assumption⁷ that the interaction potential between electrons and thermal lattice vibrations is peaked around the atomic lattice sites. In the present paper absolute intensity measurements of thermally scattered electrons shall be described which show this fact more directly.

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Experiments

The following experimental arrangement was used. A nearly parallel beam of 70 keV electrons enters a platelike perfect Si single crystal (thickness 1200 Å, preparation see⁸) which is tilted continuously through the (2, 2, 0) diffraction condition, the tilting axis being parallel to the (2, 2, 0) lattice planes. Accidental reflections are avoided largely by suitable crystal orientation. During the tilt the intensities of the transmitted beam and of the electrons scattered quasielastically (energy losses < 3 eV) into some special directions of the background are recorded, the energy analysis being performed by a filter lens⁹.

The directions of observation chosen in the experiments are indicated in the schematic diffraction pattern of Fig. 1: Besides of the transmitted beam (a) the background intensity has been recorded in directions where the scattered electrons fulfill either the same diffraction condition as the primary beam (b) or the same as the (2, 2, 0) reflected beam (c) or no diffraction condition (d). These directions have been chosen so that none of the weakly excited Bragg reflections enter the slit.

The intensities measured in the cases a)–d) are plotted in Fig. 1 as full lines in units of the incident intensity J_0 vs the angle of incidence θ of the primary beam. In the cases b) and d) results for 500 and 750 °K are given. These indicate an increase of back-



ground intensity with temperature as is expected for thermal scattering.

From the asymmetry of the transmission J_{000}/J_0 (curve a) it is seen that absorption is stronger for $\theta < \theta_B$ than for $\theta > \theta_B$, θ_B being the Bragg glancing angle. This is the wellknown anomalous absorption effect (see e. g. ¹⁰). The filtered background intensities (directions b and d) show that strong absorption ($\theta < \theta_B$) is accompanied by enhanced thermal scattering and weak absorption by relatively low thermal scattering. In direction c practically no asymmetry is observed in accordance with theory (see below).

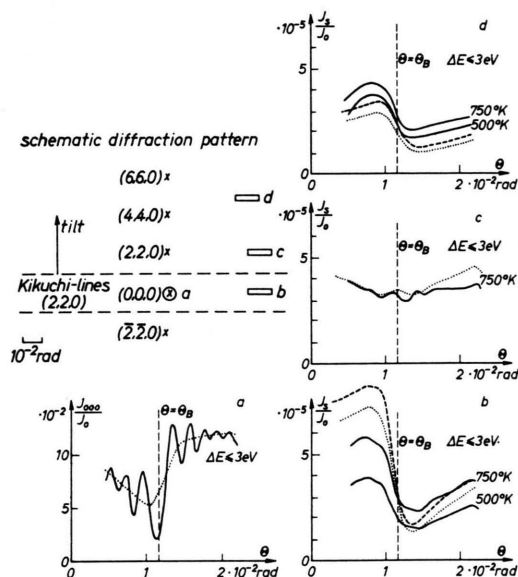


Fig. 1. Filtered intensities a) of the transmitted beam (J_{000}) and b—d) of the background (J_s) in the directions indicated in the schematic diffraction pattern, versus angle of incidence θ of the primary beam on the (2, 2, 0) lattice planes. — measured, --- calculated. J_0 = incident intensity, θ_B = Bragg glancing angle, Si crystal 1200 Å thick, 70 keV electrons.

Discussion

A qualitative discussion of the results may be based on the two beam approximation of the dynamical diffraction theory. When the incident electron wave excites only one strong Bragg reflection the wave function within the crystal can be expressed by a superposition

of two Bloch waves 1 and 2. The waves have different spatial modulations perpendicular to the reflecting lattice planes. Wave 1 has maxima of current density within the reflecting lattice planes, while the maxima of wave 2 lie between the planes. If inelastic scattering predominantly occurs near the atomic lattice sites, inelastic scattering from wave 1 and hence absorption of wave 1 is stronger than for wave 2. When the direction of the incident beam is varied, the relative intensities of the waves change in the sense that for $\theta < \theta_B$ wave 1 is predominantly excited and the reverse is true for $\theta > \theta_B$. Therefore the absorption of the total wavefield is stronger for $\theta < \theta_B$ than for $\theta > \theta_B$, as is observed in Fig. 1 a. From Fig. 1 b and 1 d it is seen that thermal scattering is strong for $\theta < \theta_B$ where wave 1 prevails and weaker for $\theta > \theta_B$. Thus it is concluded that the major part of the observed background intensity originates from Bloch wave 1, the current density of which has maxima within the lattice planes. This shows that thermal scattering occurs near the atomic lattice sites.

For a more rigorous interpretation of the results, Bragg reflection of the thermally scattered electrons, i. e. the effect of Kikuchi lines and bands, has to be taken into account. During the tilt the lines and bands move across the diffraction pattern. Especially in cases b and c one of the (2, 2, 0) band edges passes the slit when the (2, 2, 0) reflection is excited and therefore the asymmetry of curve b is enhanced in comparison to curve d (where no band-effect is expected), while in case c the asymmetry vanishes.

Calculations of the intensities have been carried out for the systematic four beam case using theoretical formulae of GJØNNES ¹¹. The equations however have been modified by suitable absorption terms, to take account of normal and anomalous absorption. The absorption parameters μ_0 and μ_h were taken from ². The scattering factors $\langle f(s-g)f(s-h) \rangle$ occurring in the equations have been calculated from the Einstein model (see ¹²) and oscillating intensity terms have been omitted for simplicity. The results are plotted in Fig. 1 as dashed lines. It is seen that the order of magnitude as well as the qualitative shape of the theoretical intensity curves is in agreement with the experiments. The remaining discrepancies are probably due to the use of the Einstein model.

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