ANOMALOUS INTERFERENCE OF ELECTRONS ON THE EDGE OF THIN FILMS

I. F. ANASKIN, I. G. STOYANOVA and E. S. KUMINOV

Biological Physics Institute, Academy of Sciences, U.S.S.R.

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Distinct interference patterns are observed on the edge of negatively charged films. The origin and nature of the interference patterns differ greatly from those due to interference on the edges of positively charged films. Anomalous interference arises as a result of the combined action of the average potential of the film and the external electrostatic field. A feature of the anomalous interference is the high visibility and constancy of the period and region of the interference pattern on varying the film potential.

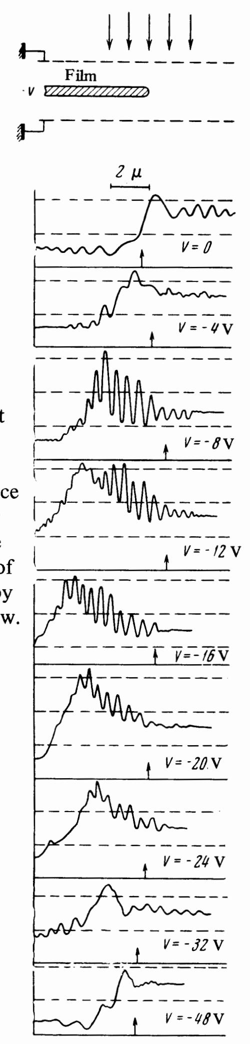

FIG. 1. Anomalous interference of electrons on the edge of thin films. a – coherent splitter of the electron wave – a thin film placed between two earthed microgrids. The arrows indicate the direction of incidence of the electron beam b – microphotometer traces of the interference images of the edge of a thin carbon film for various potentials of the film. The edge of the film is indicated by an arrow. The film is on the left of the arrow.

In our previous paper[1] we showed that the electric field on the edges of positively charged films transparent to electrons can give rise to coherent splitting of the electron wave.

In this paper we show that distinct interference patterns can also appear on the edge of negatively charged films. However, the reason for the appearance of the interference and the nature of the behavior of the interference patterns in this case differ sharply from those described in[1].

In our investigations of the anomalous interference of electrons we made use of carbon films 300—600 Å thick. The conditions under which they were investigated were analogous to those described in[1].

The setup for the coherent splitting of the electron wave and a series of microphotometer traces of the anomalous interference of electrons at various negative film potentials is shown in Fig. 1. On changing the potential from 0 to −20 volts the interference pattern shifts towards the film. On further increasing the negative potential the pattern begins to shift in the opposite direction.

The nature of the interference patterns appearing on the edge of films at negative potentials is shown in Fig. 2. The image of the film edge at zero potential is shown in Fig. 2a. The edge of the film at various potentials is marked by an arrow. The location of this edge on the interference image was determined from the positions of the characteristic elements of the film structure which were repeated in all the shadow images at various film potentials. The shifting of these details relative to the interference image of the film edge makes it possible to determine the extent of the superposition of the interference pattern on the image of the film.

As is seen from Figs. 1 and 2, the intensity of the maxima of the interference patterns appearing at negative potentials is higher than the intensity of the maxima of the diffraction pattern from the edge (V = 0).

Weak interference bands with a large period are observed on the film edge in the shadow region at large negative potentials (V = −48 volt). This pattern is similar to the diffraction pattern due to a nontransparent half-plane whose edge coincides with the edge of the film, but with the half-plane itself being located on the right.

Analysis of the interference patterns and of their microphotometer traces allows one to establish the following features of the anomalous interference of electrons:

1. The interference pattern is located in the shadow of the film and has a period which differs from that of the diffraction pattern due to the edge.

2. The period and the region of the distinct interference pattern remain constant when the potential of the film is varied.

3. The intensity of the pattern at the edge of the film in the shadow region exceeds the intensity of the pattern outside the film. As a result of this, the curve representing the average electron current density on the shadow image of the film (with averaged intensity of the interference maxima) has a broad maximum. A distinct interference pattern appears only on one side of the maximum.

4. The interference pattern has a high contrast. For V = −8 volt the ratio $(j_{max} - j_{min})/(j_{max} + j_{min}) = 0.42$ (here j_{max} and j_{min} are the current densities in the maximum and minimum of the interference pattern).

On the basis of these data the mechanism giving rise to the anomalous interference of the electrons appears to be as follows. In passing through the film the electron wave undergoes a phase shift $\Delta\varphi_f$ due to the action of the average internal potential of the film and the external electric field. Since the average internal potential of the film is always positive, the phase shift $\Delta\varphi_f$ due to the film is subtracted from the phase shift due to the external electric field of the film. For a carbon film 300–600 Å thick the phase shift $\Delta\varphi_f$ amounts in all to 0.5–1 λ (λ is the wavelength of the electron). Regardless of its small value this shift at the boundary leads to a considerable change in the nature of the form of the wave front. The anomalous interference of electrons resulting from the combined action of the average inner potential of the film and the external electrostatic field does not occur in very thin films. The nature of the change of the phase shift $\Delta\varphi$ of the electron wave for negative film potentials is shown in Fig. 3a.

On the basis of an analysis of the change of the form of the wave front in passing through the film and taking into account the experimentally observed peculiarities, the following account of the appearance of the interference seems probable[1)]. The interference pattern (Figs. 3b and 3c) appears on the background of the shadow image of the film edge as a result of the superposition of several coherent waves representing the primary wave modified by the film and an edge wave (emitted by the film edge). The edge wave represents a distortion of the wave front propagating in space; the distortion is due to the phase shift at the film edge, and is analogous to the cylindrical wave introduced to explain the diffraction phenomena.[2,3]

The unchanged nature of the period and region of interference on varying the magnitude of the negative potential allow one to assume that the form of the wave front near the film edge is almost unchanged when the potential is varied. In accordance with our conception of the mechanism giving rise to the anomalous interference, the constancy of the form of the wave front is insured by the unchanged phase shift in the film and the position of the zero equipotentials around the film. The broad maximum on the intensity distribution is due to the decreasing thickness of the film towards the edge. The presence of this section attests to the fact that this instance is not one of pure two-beam interference. The occurrence of multi-beam interference is apparently the reason for the high contrast of the interference bands.

The anomalous interference of electrons is connected with the nature of the interaction of the electron wave with the material of the film and can consequently be utilized in investigations of the structure of thin films.

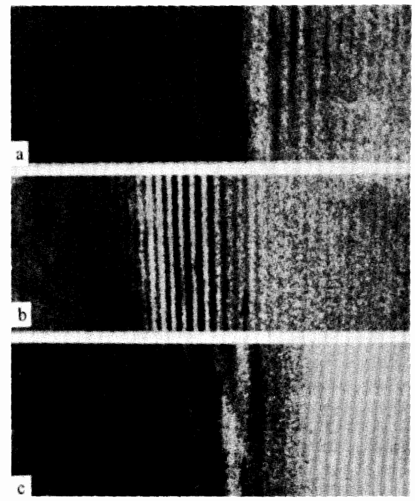

FIG. 2. Shadow image of the edge of a thin film at a film potential: a – V = 0; b – V = −8 volt; c – V = −48 volt. The geometric edge of the film is indicated by an arrow. The film is on the left of the arrow. The accelerating potential is 75 kV. Total magnification – 4000 X.

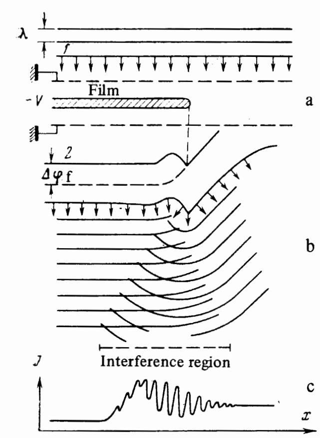

FIG. 3. Schematic diagram of the appearance of the anomalous interference of electrons. a – Change of the plane wave front on passing through the film: 1 – the wave front before the film, 2 – the wave front after passing through the film; b – superposition of the individual portions of the wave front and the appearance of interference; c – distribution of the electron current density j in the plane of observation.

1)Charging effects of the film by the electron beam do not contribute to the anomalous interference, since the interference image of the edge of the carbon film remains stable with changing illumination and and film position, and reacts without inertia to a change in the film potential. Also, the appearance of anomalous interference cannot be explained by the production of microscopic lenses on the mesh of the grid with the film, since their optical power is very small.

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[3] H. Boersch, J. Geiger, and W. Kluge, Optica Acta 10, 21 (1963).

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