Observation of the Interference Effect of Electron-Capture X-rays from Radioisotopes

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journal or publication title	CYRIC annual report
volume	1993
page range	51-53
year	1993
URL	http://hdl.handle.net/10097/49743

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Interference effect of secondary emissions from atoms has been used to determine structural data for emitting atoms, such as Kossel pattern[1,2] in a perfect crystal, and fluorescent x-ray interference (FXI)[3,4] above a mirror surface. In this report, we tried to observe the same x-ray interference without a primary probe, and we were able to see the Lloyd's mirror-type[5] interference effect of the electron-capture x-rays from radioactive atoms.

Here, we describe a new method, interference pattern from radioisotopes (IPR), for obtaining positional information about the radioactive atoms. We utilize the Lloyd's mirror-type interference effect of monochromatic x-rays from the radioactive atoms embedded in a noncrystalline material as shown in Fig 1. X-ray emissions from a radioactive atom above a substrate can take two optical paths: direct emission and totally reflected emission when the take-off angle (θ_t) is smaller than the critical angle (θ_c) for x-ray total external reflection. The coherent sources are the primary source S_1, which is the radioactive atom above a substrate, and its virtual image S_2. The optical path difference between two sources depends on both the distance (z) of the radioactive atom from the substrate and the phase shift at total reflection. Thus, positional information about the radioactive atoms can be obtained from the period of the observed interference fringes. The theoretical interference pattern from the x-ray emissions can be calculated for a characteristic matrix of stratified media on the basis of reciprocity. In other words, the calculation of the characteristic x-ray intensity from coordinate z for take-off angle θ_t is identical to that of the incident x-ray field at coordinate z for glancing angle θ_t. When radioactive atoms act as characteristic x-ray sources with distribution N, the yield Y is given by:

$$I(\theta_t, z) = | E_d + E_r |^2 \qquad (1)$$

$$Y(\theta_t) = \int N(z)\, I(\beta_t, z)\, dz, \qquad (2)$$

where I (θ_t, z) is the angular distribution of the characteristic x-rays due to interference effects between the direct and totally reflected emissions from coordinate z at the take-off angle (θ_t). E_d and E_r are E-field plane waves of the direct and reflected emissions. N(z) is the distribution of atom at a distance z from the substrate surface.

Our model sample in this experiment was a monoatomic ^{51}Cr layer embedded in an Langmuir-Blodgett film on a Pt substrate(Fig. 2). In this experiment, we took the specific radioactivity of ^{51}Cr atoms to be 470 mCi/mg. We measured the total amount (77±5 kBq) of the ^{51}Cr atoms transferred onto the Pt substrate by counting the γ-ray peak area (320 keV) using a pure Ge detector (PGT Co.).

To obtain an adequate signal-to-noise ratio for the monochromatic radiation from the ^{51}Cr atoms, we used a two-dimensional detector (an imaging plate, IP)[6] as a wide-area detector. The IP is non-energy-dispersive and the ^{51}Cr emits vanadium Kα (4.95 keV), vanadium Kβ (5.42 keV) and γ ray (320 keV). Thus, the observed interference fringes were a mixture of V Kα , V Kβ and γ rays. However, the γ rays (320 keV) were slightly absorbed through the Pt substrate. Thus, the intensity of the IP between -3 and zero mrad was defined as the intensity zero for subtracting the intensity of both the γ rays and radiation from environment in the IP. The distance from the sample to the detector was 300 mm. The IP detector size was about 127x127 mm (BAS-UR). The experiment was carried out in prepurified helium gas to decrease the absorption of x-rays, and in a 10 mm-thick Pb shield box to suppress background signals. The exposure time was 6 days. The IP was read out by a BAS-3000 system (Fuji Photo Film Co., Ltd.). We measured three clear fringes(Fig. 3).

Acknowledgments

We are grateful to Prof. T. Ido of CYRIC and Dr. K. Mori of Fuji Photo Film Co., Ltd. for providing the IP plate and IP reader.

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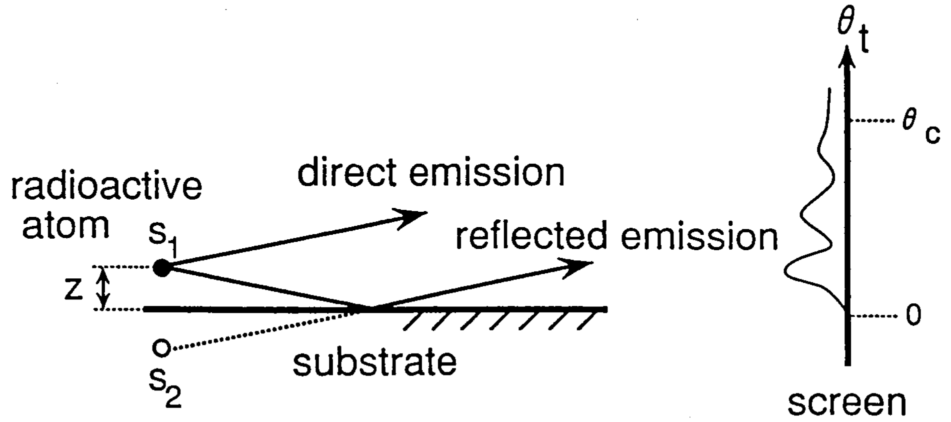

Fig. 1. Schematic of the interference phenomenon of the electron-capture x-ray from a radioactive atom embedded within a sample. Z represents the distance between the radioactive atom and the substrate surface. θ_t is the take-off angle of the electron-capture x-rays. The model interference fringes under θ_c is shown on the screen.

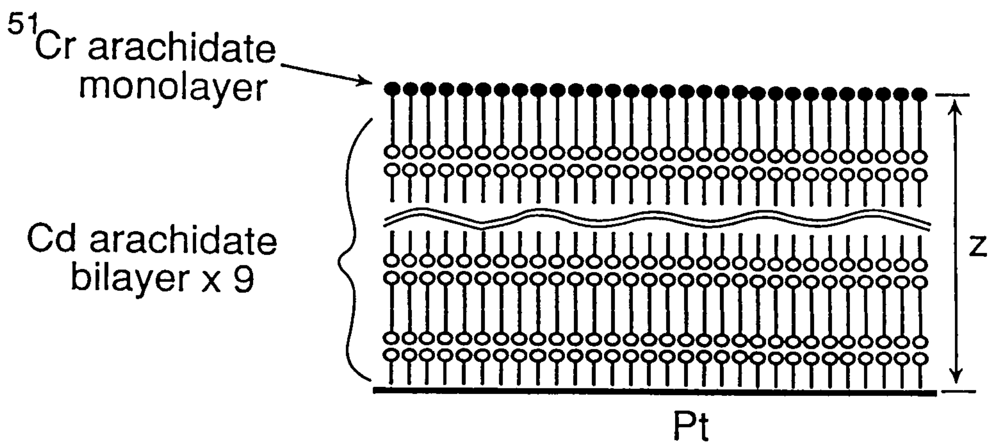

Fig. 2. Structure of the sample.

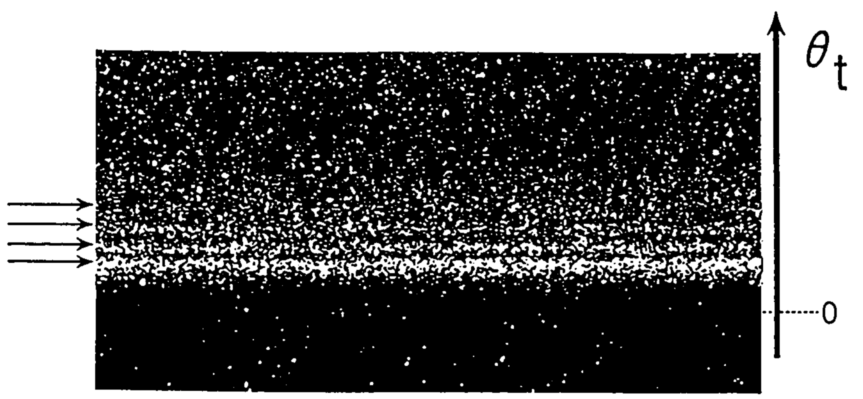

Fig. 3. Interference fringes of the electron-capture x-ray from the ^{51}Cr monolayer with the IP. The exposure time was 6 days. High intensity areas of the measured x-rays are shown by the arrows.