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Compton scattering of 59.5 keV gamma rays from p-Si sample in an external electric field

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Abstract

This study is related to Compton scattering of photons from a p-Si sample whose surface charge density distributions are changed by an external electric field. The external electric field intensity in the range 0–75 kV/m was used to change the surface charge density distributions of the sample. The sample surface perpendicular to the electric field was selected as the scattering surface. The p-Si sample was bombarded by 59.5 keV γ-photons emitting from an Am-241 point source. The Compton scattered photons at an angle of 90° were detected by an Si(Li) detector. The Compton scattering intensity suddenly increased with the application of the electric field since the applied electric field distorts both the negatively charged scattering center (free electron, bound electron, ionized acceptor) and the positively charged scattering center (hole) and their momentum distribution in the sample. There is a good third-order polynominal relation between the Compton scattering intensity and the increasing (or decreasing) electric field intensity. The results show that the positively charged scattering centers behave like negatively charged scattering centers, but the latter are slightly more effective than the former in the Compton scattering of γ-rays from the sample in the electric field.

Keywords: Compton scattering; External electric field

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1. Introduction

Compton scattering refers to the interaction of γ- and X-ray quanta with free electrons and those atomic electrons whose binding energies are much less than the energy transferred on scattering. Compton scattering with γ-rays is a well-known tool for probing the momentum distribution of valence and conduction electrons in solids. In the process, the photon imparts some of its energy to the electron, and the energy of the scattered photon is given by the equation

$$E_s = \frac{E_i}{1 + (E_i/m_0c^2)(1 - \cos\phi)}, \tag{1}$$

where m_0 the mass of an electron at rest, c the velocity of light, ϕ the angle between the directions of the incident and the scattered photons, and E_i and E_s the energies of the incident and scattered photons, respectively.

In the Compton scattering experiment, the emerging beam is Doppler broadened because the atomic electrons move around the atomic nucleus. In recent years, several studies have analyzed this broadened line shape (Compton profile), which is sensitive to the momentum distribution of loosely bound valence electrons and provides information about the electronic momentum distribution of the bound target electrons on the scattering wavevector [1,2].

The Klein–Nishina theory predicts that Compton scattering is particularly sensitive to the valence electrons. If the energy transferred to the electron in the Compton scattering process is much longer than the electron binding energy, the so-called impulse approximation is valid [3].

The theoretical incoherent differential-scattering cross section per atom is calculated by using the following equation given by Hubbell et al. [4]:

$$\frac{d\sigma_{inc}}{d\Omega} = \frac{d\sigma_{KN}}{d\Omega} S(x, Z). \tag{2}$$

Here, $d\sigma_{KN}/d\Omega$ is the Klein–Nishina prediction for the Compton scattering cross section at the same angle per electron assumed free and at rest:

$$\frac{d\sigma_{KN}}{d\Omega} = \frac{r_e^2}{2}[1 + k(1 - \cos\phi)]^{-2} \times \left[1 + \cos^2\phi + \frac{k^2(1 - \cos\phi)^2}{1 + k(1 - \cos\phi)}\right], \tag{3}$$

where r_e is the classical electron radius, k is the photon energy in units of the electron rest-mass energy, and ϕ is as described in Eq. (1). For the mathematical description of photon scattering from an atomic electron, the perturbation of the other electrons in the atom is customarily considered in terms of the incoherent scattering function $S(x, Z)$, where Z is the atomic number and $x = \sin(\phi/2)/\lambda$ is the momentum transfer (λ is the wavelength of the incident γ-ray).

In this work, the negatively and positively charged scattering charge center densities in the scattering surface of the semiconductor sample at room temperature have been changed by applying an external electric field and the Compton scattering experiment has been performed. Our motivation in performing this experiment has been twofold. First, all the charge centers contribute to the Compton spectrum and the part associated with the valence electrons, ionized acceptors and holes are of primary interest. We wanted to show the sensitivity of Compton scattering to charge centers by changing the ionized acceptor and hole densities with the external