X-Ray linear polarization degree for RGL beamline BESSY II

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Abstract. The results of the calculation of the X-Ray synchrotron radiation linear polarization degree of Russian-German dipole beamline at synchrotron BESSY II are discussed. It is shown that the integral synchrotron radiation linear polarization degree \((\lambda, \psi_h)\) for incident photon energy \(\epsilon=300\text{eV}\) reaches 80%.

1. Introduction
One of the unique and useful property of synchrotron radiation for soft X-Ray spectral analysis with incident photon energy from 10 to 1200 eV is high polarization degree \(P\) \cite{1}. High degree of this parameter is crucial for soft X-ray absorption coefficient determination of graphene-like structures or linear and planar molecules adsorbed on the surface. Such structures are characterized by stable position of free molecules orbitals with pi- and sigma-symmetry lying perpendicular to molecular plane and along the molecular axis, correspondingly.

The selection of high polarized beam or calculation of its linear polarization degree allow us to determine the adsorbed molecule orientation or to provide the experimental measurements of absorption coefficient in soft X-ray range for electron transition from core level to free molecular orbital of pi- and sigma- symmetry separately and independently of each other. The linear polarization degree of synchrotron source depends not only on synchrotron parameters but beamline equipment and may vary for given synchrotron depending on beamline.

In current work the linear polarization degree of synchrotron radiation from Russian-German dipole beamline (RGL) \cite{2} at synchrotron BESSY II is calculated. The RGL is aimed to high resolution photoemission and photoabsorption research in the soft X-ray photon-energy region (30–1500 eV). The calculation was based on theoretical approach of Kunz \cite{3} and performed for different photon energies (\(\epsilon=40, 200, 300, 500, 800\text{ eV}\)).

2. The polarization of synchrotron radiation
It is well known, that synchrotron radiation, in general, is characterized by elliptical polarization included two electron field vector components \(E_\parallel\) and \(E_\perp\), which are parallel and perpendicular to electrons rotation orbit plane. The direction of elliptical polarization rotation is changed when the radiation passes through the rotation plane of radiating electrons and exactly in the electrons rotation plane the radiation is characterized by the highest degree of linear polarization. The theoretical and
experimental researches show the parallel and perpendicular components distributed with maximum and minimum lying in orbit plane, respectively (Figure 1) [4], that leads to extremely high linear polarization degree with parallel component $E_{II}$ exactly in the electron orbit plane. However, it is well seen from the Figure 1 that on practice perpendicular component doesn’t drop to zero in orbit plane direction which means that even in the orbit plane the radiation is not strictly linearly polarized and include small amount of perpendicular component $E_{\perp}$.

Figure 1. Parallel and perpendicular components of Synchrotron radiation depending on vertical angle $\psi_h$ between radiation direction and orbit plane estimated theoretically (lines) and measured experimentally at synchrotron NBS with energy $E=180$ eV for radiation with wavelength $\lambda=500$ nm (dots) [4].

Figure 2. The radiation intensity with parallel $I_{II}$ and perpendicular $I_{\perp}$ linear polarization component depending on vertical angle $\psi$ for different photon energies.
The high linear polarization degree of about the 98% can be reached by the cutting out of radiation in a small vertical angle near the electron orbit plane by the entrance slit reduction [4, 5]. On the other hand in the cause of soft X-ray spectroscopy with a diffraction grating as the dispersing element such slit size reduction leads to decreasing of soft X-ray component intensity in incident radiation, increasing of hard X-Ray intensity contribution and as a result increasing of second and higher order diffraction background radiation. Such soft (low energy) and hard (high energy, more than 1200 eV) X-ray component distribution depending on the exit slit vertical angle is clearly observed in the Figure 2 where the radiation intensity with parallel and perpendicular polarization component depending on the vertical angle from electron rotation orbit plane for different photon energy (ε =40, 200, 300, 500, 800, 1500, 3000 eV) are shown.

3. Calculations details

The calculation of synchrotron radiation intensity \( I(\lambda, \psi) \) and its parallel \( I_{||}(\lambda, \psi) \) and perpendicular \( I_{\perp}(\lambda, \psi) \) components dependent on the photon wavelength \( \lambda \) (or energy \( \epsilon \)) and vertical angle \( \psi \) between radiation direction and orbit plane was performed by the formulas (1-3) [3]:

\[
I(\lambda, \psi) = \frac{27}{32\pi^2} \cdot \frac{e^2 c}{R^4} \left( \frac{\lambda_c}{\lambda} \right)^4 \gamma^3 [1 + (\gamma \psi)^2] \left[ K_{2/3}^2(\xi) + \frac{(\gamma \psi)^2}{1 + (\gamma \psi)^2} K_{1/3}^2(\xi) \right],
\]

\[
I_{\perp}(\lambda, \psi) = \frac{27}{32\pi^2} \cdot \frac{e^2 c}{R^4} \left( \frac{\lambda_c}{\lambda} \right)^4 \gamma^3 [1 + (\gamma \psi)^2] \frac{(\gamma \psi)^2}{1 + (\gamma \psi)^2} K_{1/3}^2(\xi),
\]

\[
I_{||}(\lambda, \psi) = \frac{27}{32\pi^2} \cdot \frac{e^2 c}{R^4} \left( \frac{\lambda_c}{\lambda} \right)^4 \gamma^3 [1 + (\gamma \psi)^2] \frac{(\gamma \psi)^2}{2} K_{2/3}^2(\xi),
\]

where \( \gamma = \frac{E}{mc^2} \) - relativistic factor, \( \lambda_c = \frac{0.4\pi R}{3\gamma^3} = \frac{0.559 R}{\epsilon^3} \) is critical wavelength, \( R \) - electron orbit radius and \( K_{2/3}(\xi) \) and \( K_{1/3}(\xi) \) are Bessel functions of the second kind.

![Figure 3. Optical layout of the Russian–German beamline at BESSY [4]](image)

In the cause of RGBL beamline it’s optical layout doesn’t include entrance slit (see figure 3) and thus the equipment of this beamline doesn’t allow reducing the linear polarization degree by entrance slit size reduction. The solution of this problem is to calculate theoretically the linear polarization degree by the formula (4) and then remove the effect of \( E_z \)-component from experimental absorption spectra.
The linear polarization $P(\lambda, \psi)$ of synchrotron radiation dipole source depends on emitted photon wavelength $\lambda$ (or energy $\varepsilon$) and vertical angle $\psi$ between radiation direction and orbit plane and may be calculated as [3]:

$$P = \frac{E_{||}^2}{E_{||}^2 + E_{\perp}^2} = \frac{I_{||}}{I_{||} + I_{\perp}}, \quad (4)$$

$$P = \frac{K_{2/3}^2(\xi)}{K_{2/3}^2(\xi) + \frac{(\gamma\psi)^2}{1 + (\gamma\psi)^2} K_{1/3}^2(\xi)}, \quad \xi = \frac{\lambda}{2\lambda_c} \left[ 1 + (\gamma\psi)^2 \right]^{3/2}, \quad (5)$$

For synchrotron BESSY II the following values are used: $E=1.7$ GeV and $\lambda_c=0.495$ nm ($\varepsilon_c=2.5$ KeV).

It is clearly seen from figure 3 that at RGBL the focusing toroidal mirror of width $w=750$ mm and height $h=60$ mm positioned at an angle of 85° to the incident radiation beam is used as the entrance slit. The mirror cuts out the synchrotron radiation in the vertical and horizontal angles $\psi_w \approx 2.5$ and $\psi_h \approx 3$ mrad and focuses it to plane-grating monochromator.

4. Result and discussion

The results of the linear polarization $P(\lambda, \psi)$ of synchrotron radiation calculation for different photon energies ($\varepsilon=40, 200, 300, 500, 800$ eV) performed according to the formula (5) are shown in the figure 4. The integral linear polarization $P(\lambda, \psi_h)$ for vertical angle range $\theta-\psi_h$ and for different photon energies ($\varepsilon=40, 200, 300, 500, 800$ eV) are shown in Figure 5.

**Figure 4.** The linear polarization degree $P(\lambda, \psi)$ depending on vertical angle $\psi$ for different photon energies ($\varepsilon=40, 200, 300, 500, 800$ eV) for RGBL BESSY II.

**Figure 5.** The integral linear polarization $P(\lambda, \psi_h)$ depending on vertical angle range $\theta-\psi_h$ and for different photon energies ($\varepsilon=40, 200, 300, 500, 800$ eV) for RGBL BESSY II.
The calculated results (see figure 4, 5) demonstrate that for the energy range 200–800 eV the integral synchrotron radiation linear polarization of RGBL BESSY II lies in interval 0.75–0.85 (75-85%) and for photon energies $\varepsilon=40, 200, 300, 500, 800$ eV it is equal to $P(40)=0.76$, $P(200)=0.78$, $P(300)=0.79$, $P(500)=0.81$, $P(800)=0.83$, respectively. For the energy range of carbon atom 1s-absorption edge (280–320eV) the integral synchrotron radiation linear polarization of RGBL BESSY II reaches 80%.

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