First Observation of Scattering of Sub-GeV Electrons in Ultrathin Si Crystal at Planar Alignment and Relevance to Crystal-assisted Rainbow Scattering

Y. Takabayashi\textsuperscript{a}, Yu. L. Pivovarov\textsuperscript{b}, T. A. Tukhfatullin\textsuperscript{b}

\textsuperscript{a}SAGA Light Source, 8-7 Yayoigaoka, Tosu, Saga 841-0005, Japan
\textsuperscript{b}National Research Tomsk Polytechnic University, Tomsk 634050, Russia
Continuation of experimental and theoretical studies of the scattering of 255 MeV electrons by aligned crystals at SAGA-LS accelerator facility and TPU.

In the previous series of experiments we studied the

The goal of the present work is experimental and theoretical search for another type of scattering named rainbow scattering (RS).

We perform experimental studies and computer simulations of 255 MeV electrons scattering in an ultrathin 0.58 micrometer (111) Si crystal.


The very precise studies of crystal-assisted RS in the case of non-relativistic ions were performed by N. Nešković (L. Živković, S. Petrović, S. Kossionides, N. Nešković, Phys. Lett. A 286 (2001) 292).
The key aspect of the crystal rainbows is an unusual dependence of the deflection angle on the impact parameter with a crystal axis.

The RS for high-energy electrons (100 and 500 MeV) at axial alignment was theoretically considered in (L. Živkovi´c, S. Petrovi´c, S. Kossionides, N. Neškovi´c, Phys. Lett. A 286 (2001) 292) using both classical and quantum approaches and Lindhard’s string potential.

The theory predicted some contradictions between classical and quantum approaches.

## SAGA Light Source (SAGA-LS), Tosu, Saga, Japan

### Storage ring
- **Circumference**: 75.6 m
- **Energy**: 1.4 GeV
- **Stored current**: 300 mA
- **Emittance**: 25 nm\(^2\)rad
- **Lifetime**: 6 hours @300 mA
- **Critical energy**: 1.9 keV

### Injector linac
- **Total length**: 30 m
- **Energy**: 255 MeV
- **Average current**: 7 nA
- **Repetition**: 1 Hz
- **Normalized emittance**: 25 mm\(^2\)mrad
- 255 MeV e\( ^{-} \) 0.47-\( m \)-thick Si crystal
- (111) planar alignment
- The effective thickness of the crystal 0.47 \( \times \cos(35.3^\circ) \) \( \approx \) 0.58 \( m \)
- Collimator with an inner diameter of 100 \( m \) upstream of the crystal
- The beam intensity at the crystal is considered to be constant within a diameter of 100 \( m \).
- The angular divergences of the incident beam: \( \theta_{x} \approx 0.09 \text{ mrad} \) and \( \theta_{y} \approx 0.05 \text{ mrad} \)
Results of Rainbow Scattering Experiment

2D profile:

$\theta = 0^\circ$

$\theta = 0.014 \frac{\theta_c}{2}$

$\theta = 0.028 \frac{\theta_c}{2}$

Horizontal projected profile: $I(x) = \int dy I(x, y)$

Horizontal cross-sectional profile: $I(x) = I(x, 0)$
Angular Distribution Simulation

- **Equation of motion**
  \[\gamma m \ddot{x} = F_x = -\frac{\partial U(x)}{\partial x}, \quad \gamma m \ddot{z} = 0\]

- **Initial conditions**
  \[x(0) \equiv x_0\]
  \[v_x(0) = c \sqrt{1 - \frac{1}{\gamma^2}} \sin(\theta)\]

Angular Distribution Simulation

Scattering angle vs longitudinal coordinate

Electrons, $E=255$ MeV, $L=0.58$ $\mu$m, $\theta=0.0^\circ$

$\theta_x = v_x / c$
Electrons, $E=255$ MeV, $L=0.58 \mu m$, $\theta=0.0^o$
Angular Distribution Simulation

Electrons, $E=255$ MeV, $L=0.58$ µm, $\theta=0.0^\circ$

Spatial distribution

Angular distribution

$z=0.58$ µm
Angular Distribution Simulation

The exit angles of the electrons vs the point of entry

Electrons, E=255 MeV, L=0.58 \( \mu \text{m} \), \( \theta=0.0^\circ \)

Electrons, E=255 MeV, L=0.1 \( \mu \text{m} \), \( \theta=0.0^\circ \)

Red line is the gradient of potential in arbitrary unit
Results of Rainbow Scattering Experiment

2D profile: Simulation

Horizontal cross-sectional $I(x) = I(x,0)$ Simulation (dashed line), experiment (solid line)

$\theta = 0^\circ$

$\theta = 0.014 \frac{\theta_c}{2}$

$\theta = 0.028 \frac{\theta_c}{2}$
Conclusions

- The new experiments on channeling of 255 MeV electrons in an ultrathin Si crystal were performed at SAGA LS facilities.
- Rainbow scattering for relativistic electrons in an ultra-thin Si crystal for (111) planar alignment were observed.
- The simulations of trajectories at (111) planar channeling in Si, angular, spatial distributions of electrons have been performed taking into account initial spatial and angular divergence of the electron beam.
- Comparison of the experimental and theoretical results shows a good agreement.
THANK
FOR YOUR
ATTENTION!
Comparison with experiment

Electrons, $E=255$ MeV, $L=0.58$ μm, $\theta=0.0^\circ$