Planar channeling radiation by relativistic electrons in different structures of silicon carbide

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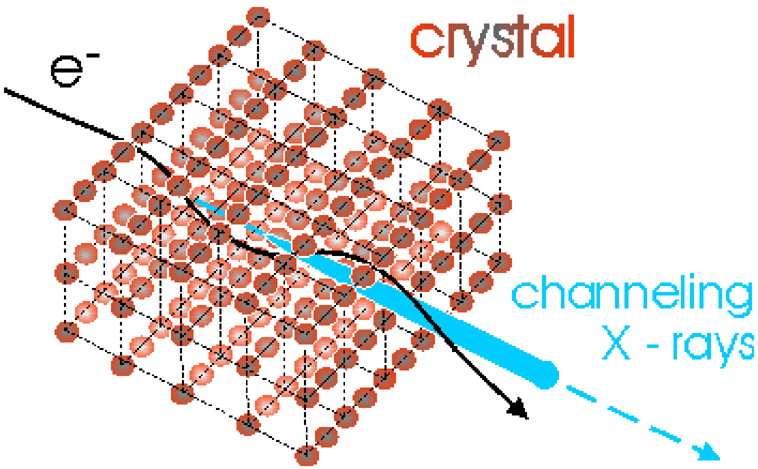
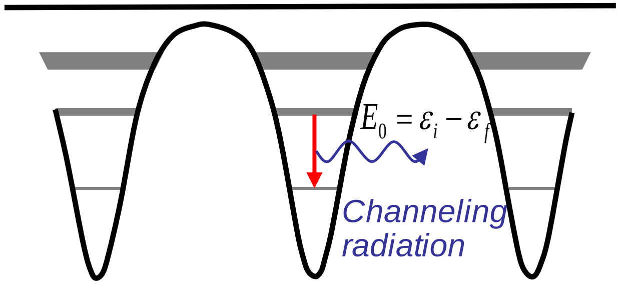
Outline

1. **Motivation**
2. **Theory of channeling radiation (CR)**
3. **CR measurements on cubic and hexagonal structures**
4. **Channeling radiation in different structures of SiC**
5. **Summary**

1. Theory of planar channeling radiation





$$E_X(\theta) = \frac{2\gamma^2 E_0}{(1+\gamma^2\theta^2)} \qquad \theta < \frac{1}{\gamma}$$

γ - Lorentz factor

θ - observation angle

CR properties

- quasi-monochromatic
- directed
- intense
- tunable

1. Theory of planar channeling radiation (quantum mechanical)

Continuum potential:

$$V(x) = \sum_n v_n e^{ingx}$$

$$v_n = -\frac{2\pi}{V_c} a_0^2 (e^2/a_0) \sum_j e^{-M_j(\vec{g})} e^{-i\vec{g}.\vec{r}_j} \sum_{i=1}^{4} a_i e^{\left(-\frac{1}{4}\left(\frac{b_i}{4\pi^2}\right)(ng)^2\right)}$$

Quantum mechanical model $E_e < 100\, MeV$

$$-\frac{\hbar^2}{2m_e\gamma}\frac{d^2\psi(x)}{dx^2} + V(x)\psi(x) = E\psi(x)$$ ⇒ Wave functions $\psi_i(x)$ and E_i eigenvalues

$$\frac{d^2N_{CR}(i\to f)}{d\Omega_\gamma dE_\gamma} = \frac{\alpha\lambda_c^2}{\pi\hbar c} 2\gamma^2(\varepsilon_i - \varepsilon_f) \left| \left\langle \psi_f(x) \left| \frac{d}{dx} \right| \psi_i(x) \right\rangle \right|^2 \int_0^z dz P_i(z) \times \frac{\Gamma_{\text{tot}}/2}{(E_\gamma - E_0)^2 + 0.25\Gamma_{\text{tot}}^2}$$ ⇒ CR intensity

$$E_0^k = 2\gamma^2(E_{ki} - E_{kf})$$ ⇒ CR photon energy

1. Theory of planar channeling radiation (classical)

Classical model $E_e > 100\,MeV$

Planar continuum model: $\gamma m \ddot{x}(t) = F = -\frac{\partial V(x)}{\partial x}$

Initial conditions :
$$\vec{r}_{\perp 0} = x_0 \hat{x}$$
$$\vec{p}_{\perp} = \gamma m \dot{x}_0 \hat{x}$$

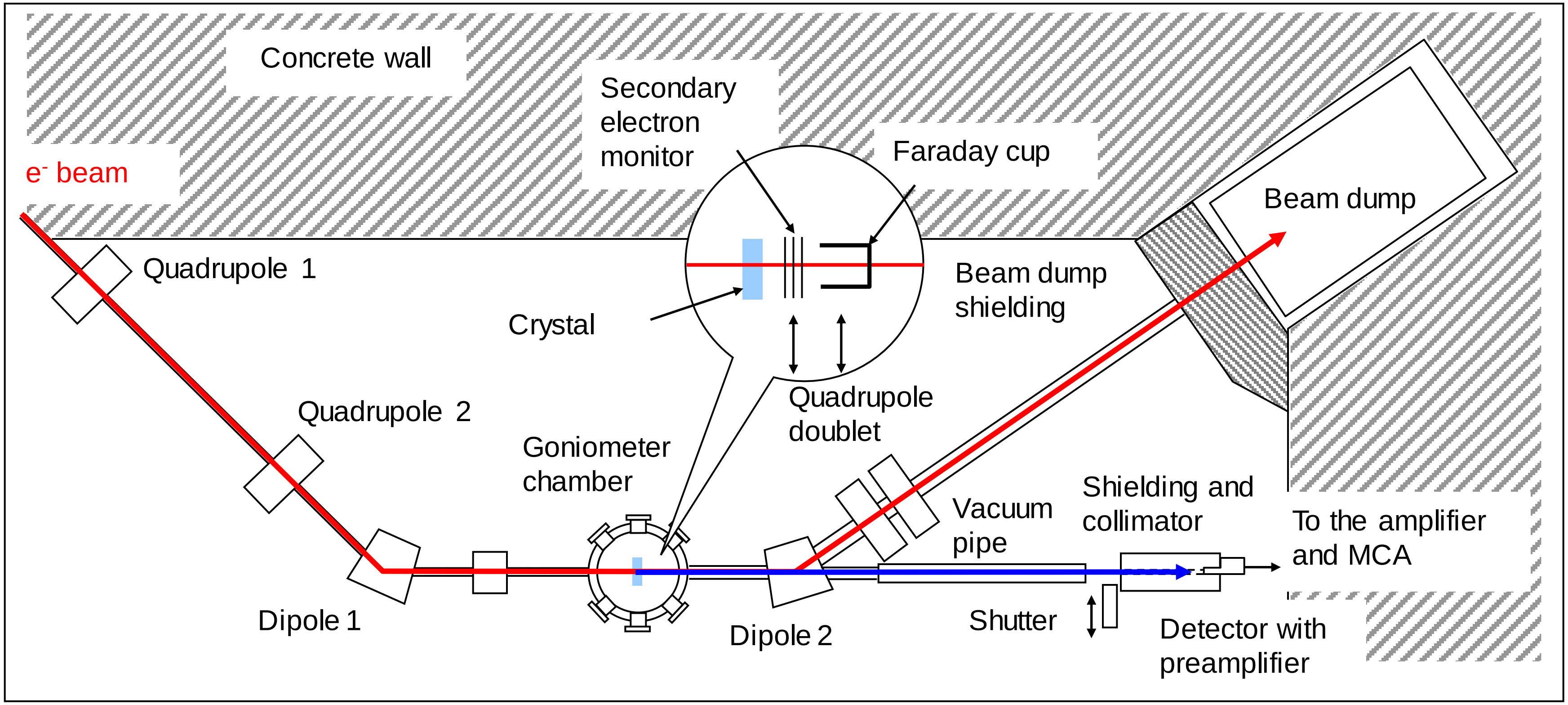
Energy density:

$$\frac{d^2 E}{d\omega d\Omega} = \frac{e^2}{4\pi^2 c} \left| \int_0^{\tau} e^{i(\omega t - \vec{k}.\vec{r})} \frac{\vec{n} \times ((\vec{n} - \vec{\beta}) \times \dot{\vec{\beta}})}{(1 - \vec{\beta}.\vec{n})^2} dt \right|^2$$

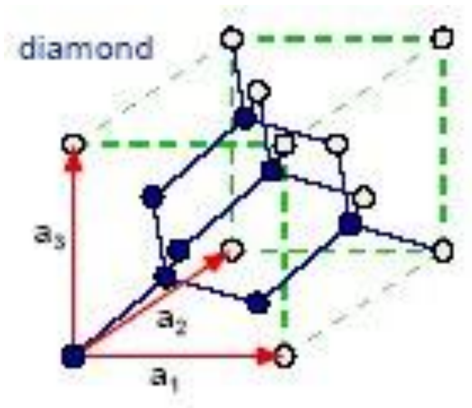
$$\vec{\beta} = \dot{\vec{r}}(t) / c$$

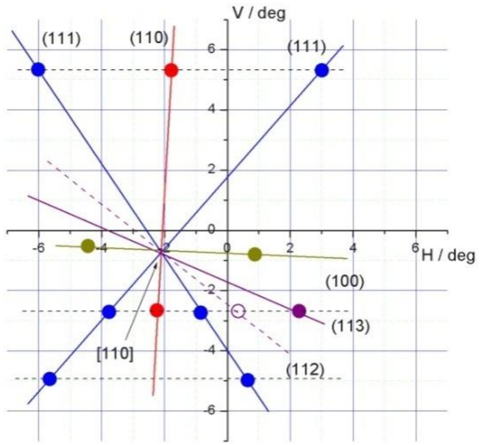
$$\vec{r}(t) = \vec{v}_z t + \vec{x}(t)$$

3. CR measurements on cubic and hexagonal structures



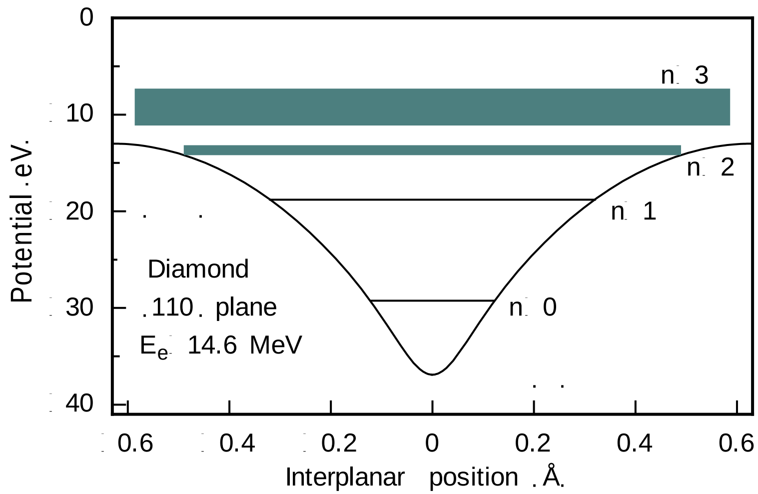
3. CR measurements on cubic structures

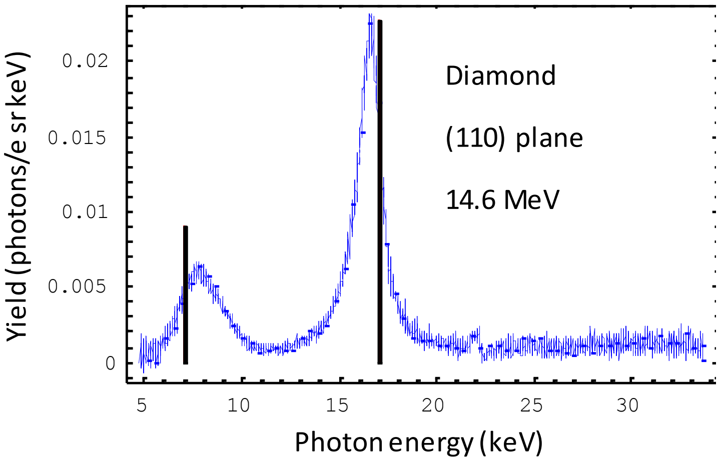




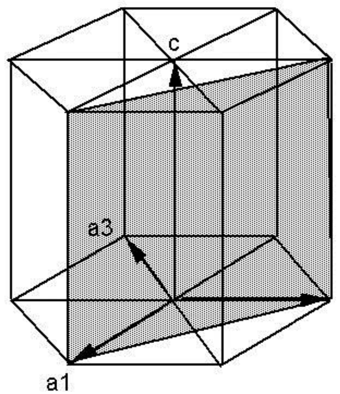
Diamond structure: Diamond, Si,Ge

Map of diamond crystal constructed from planar scans

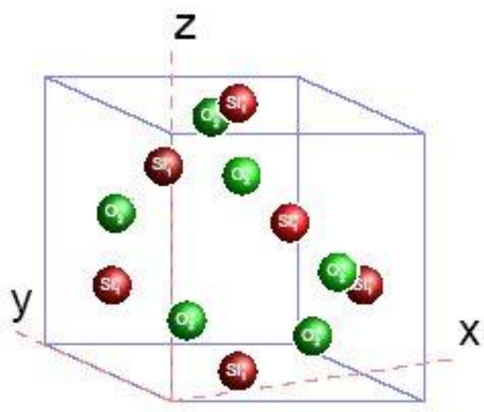




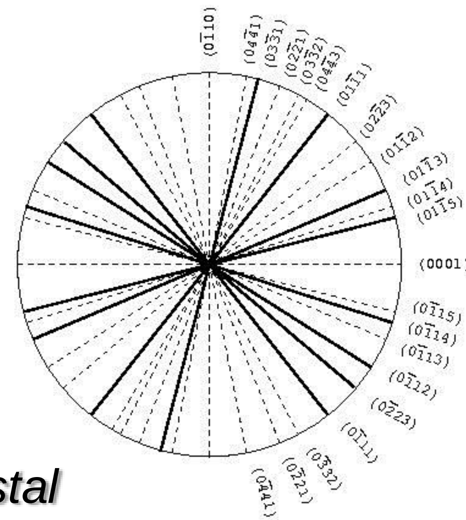
3. CR measurements on Hexagonal structures



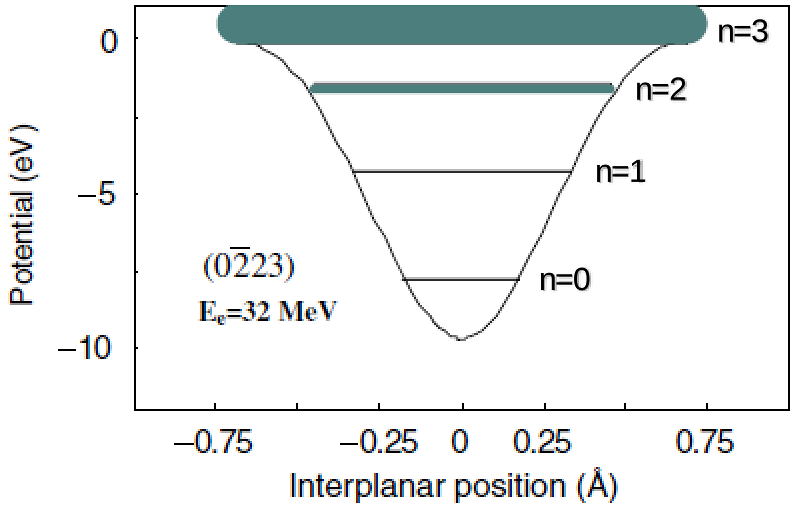
Hexagonal structure of quartz

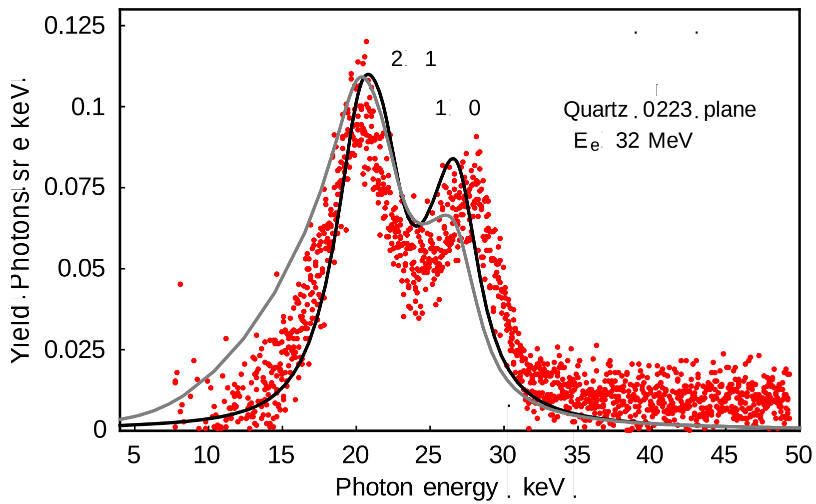


Unit cell of the quartz crystal

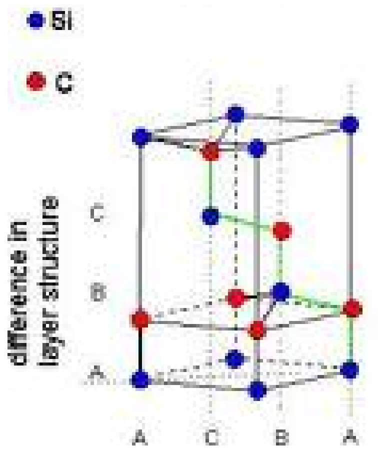


Zone of crystal planes perpendicular to the axis $[2\bar{1}\bar{1}0]$





This is one possible stacking (ABCABC) for tetrahedral structures



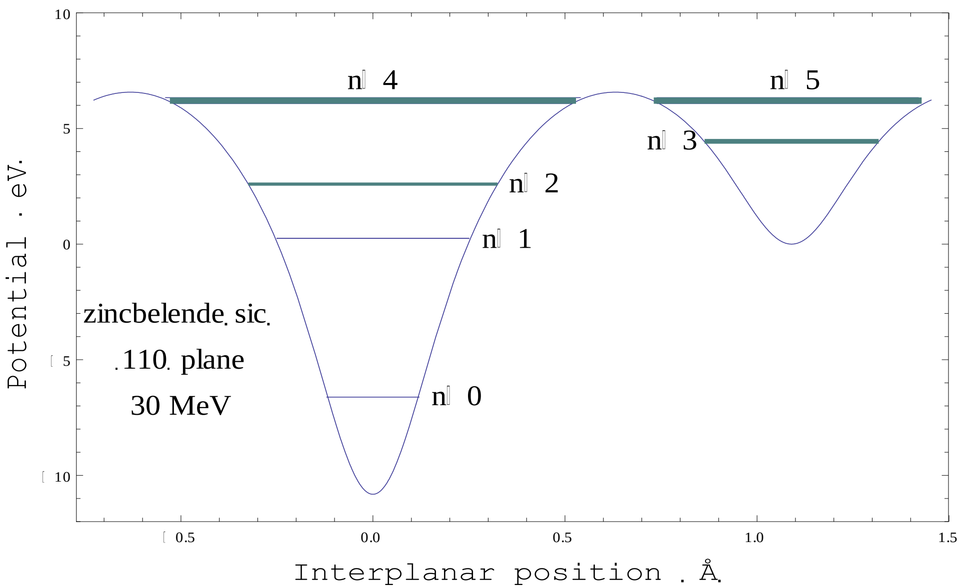
Space Group: F43m

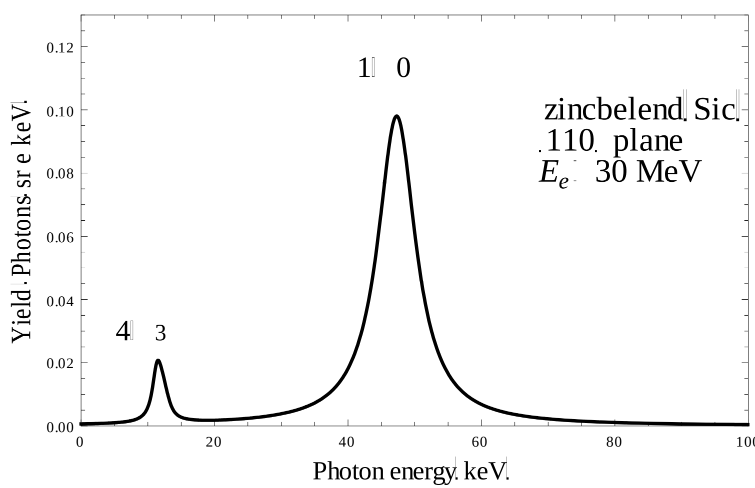
Number: 216

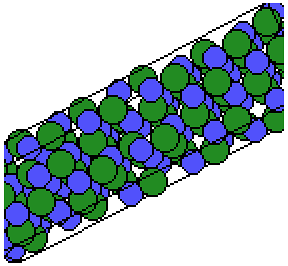
Rhombohedral structure

Miller indices (hkl)

CR from planes with Miller indices h=0 or k=0 or l=0 will be observed.







Space Group: R3m

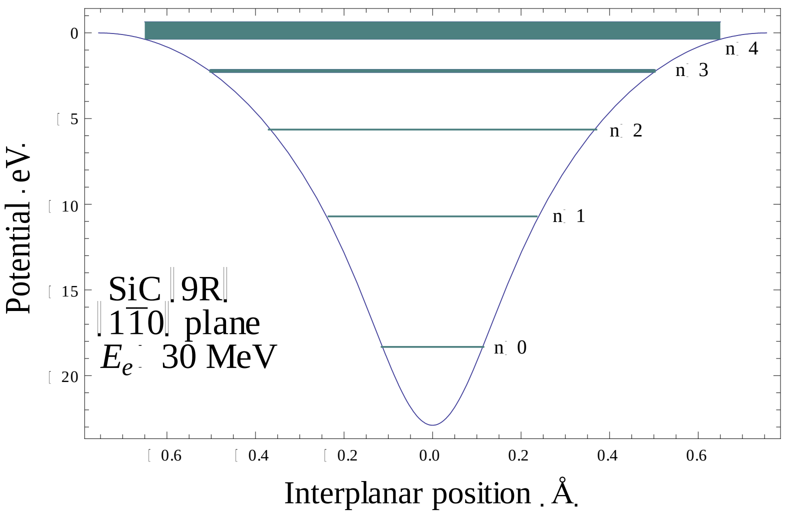
Number: 160

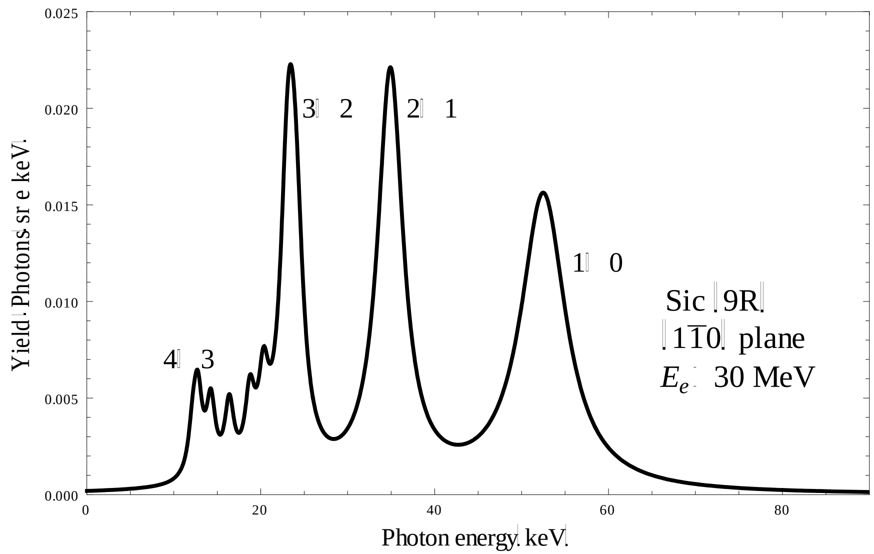
Rhombohedral structure

Miller indices (hkl)

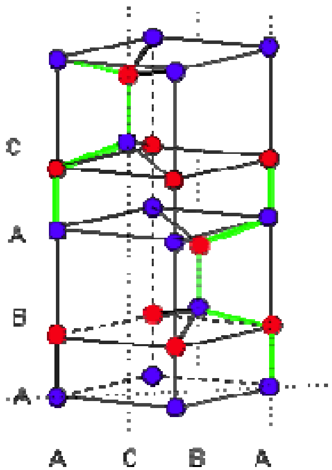
This is a hypothetical alternate stacking (ABCBCACAB) for tetrahedral structures.

CR from planes with Miller indices l=0 and h=-k will be observed.





SiC 4H

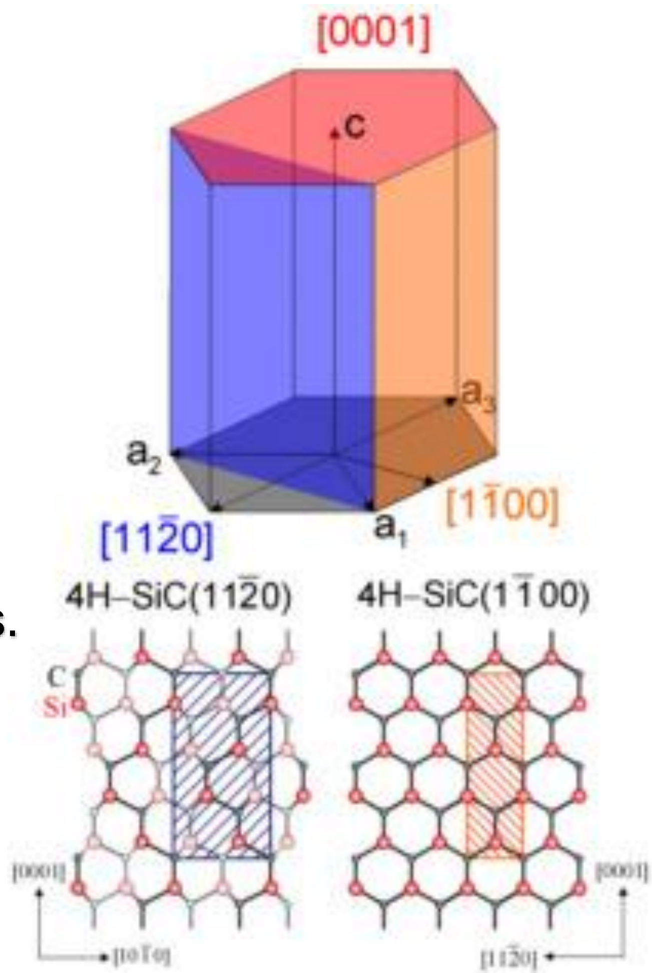


This is one possible stacking (ABAC) for tetrahedral structures.

The 4H refers to the fact that there are 4 CSi dimers in a hexagonal unit cell.

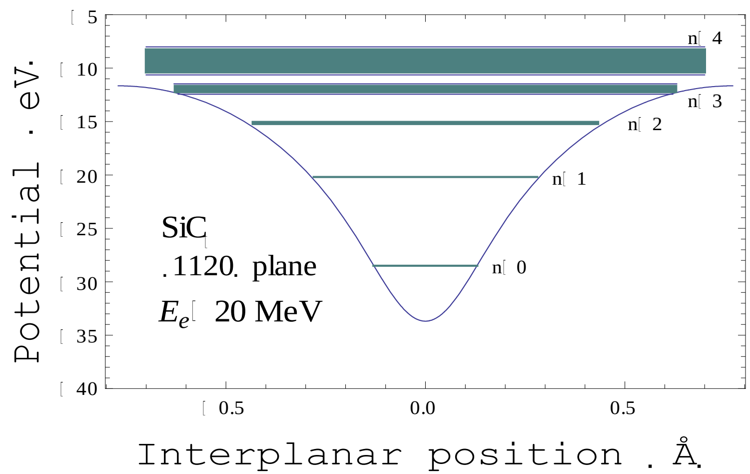
[Space Group: $P6_3mc$]

Number: [186]

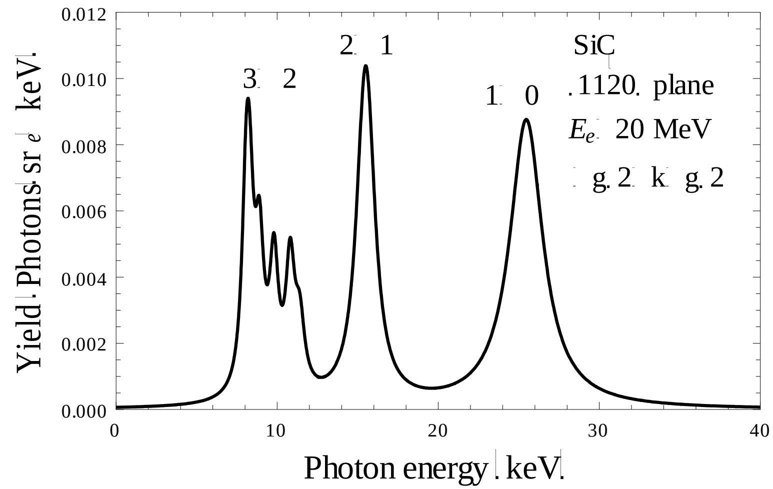


Hegxagonal structure
Miller indices (hkil)
i=-(h+k)

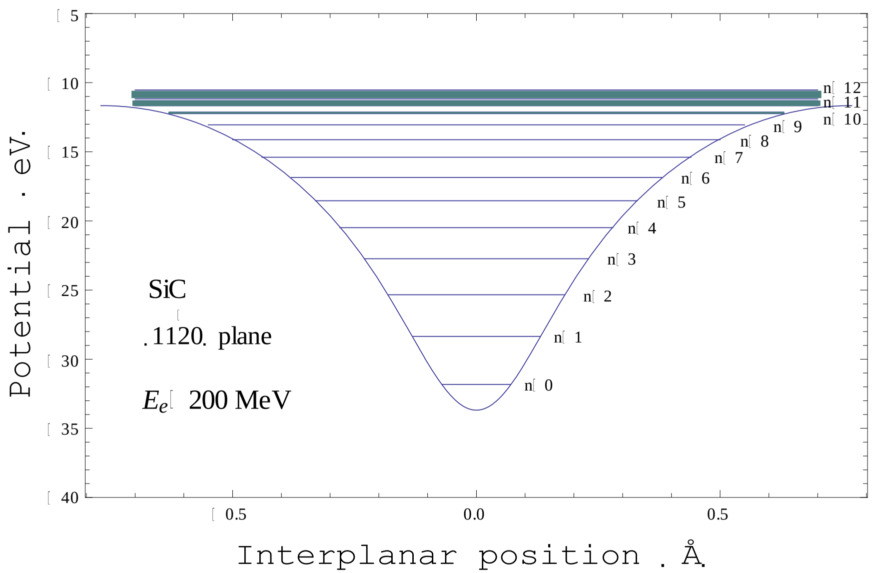
SiC 4H belongs to the space group $P6_3m$ and the CR from planes with Miller indices l=0 will be observed.



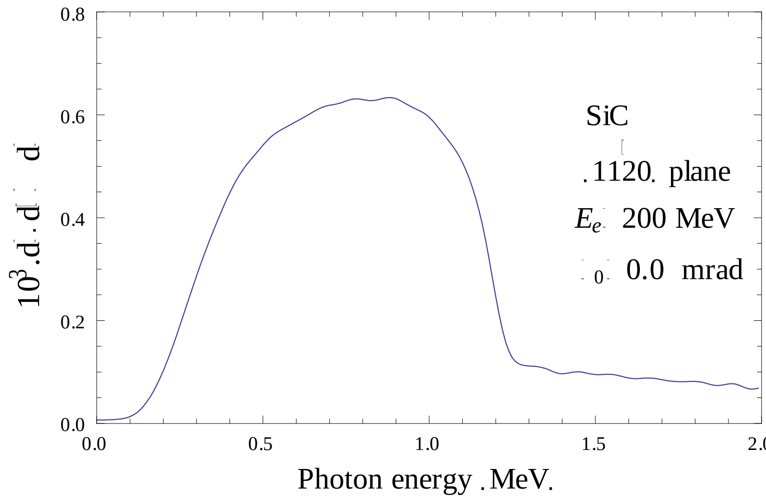
Potential . eV.
Interplanar position . Å.
SiC
.1120. plane
E_e 20 MeV
n 0
n 1
n 2
n 3
n 4



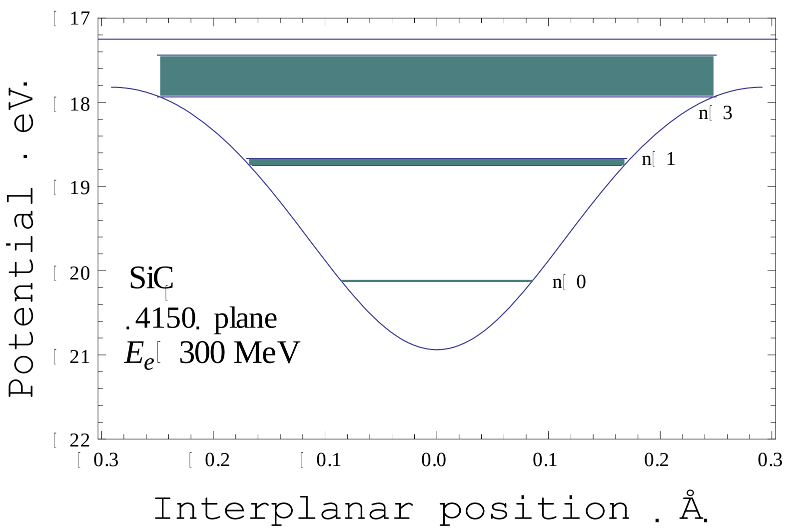
Yield . Photons sr e keV.
Photon energy . keV.
3 2
2 1
1 0
SiC
.1120. plane
E_e 20 MeV
g. 2 k g. 2

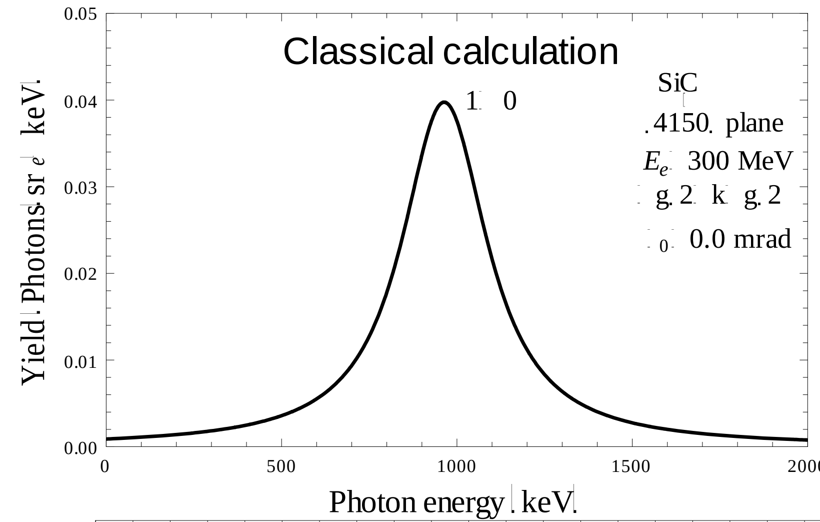


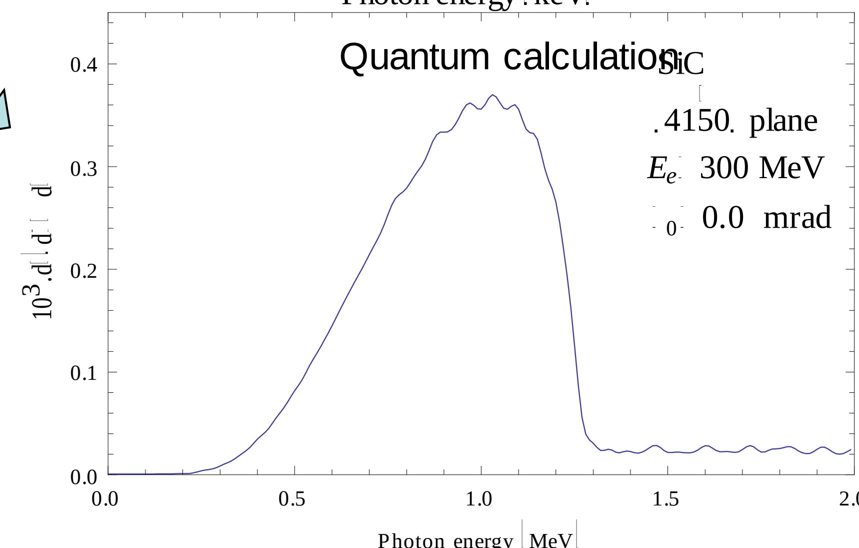
Potential . eV.
Interplanar position . Å.
SiC
.1120. plane
E_e 200 MeV
n 0
n 1
n 2
n 3
n 4
n 5
n 6
n 7
n 8
n 9
n 10
n 11
n 12



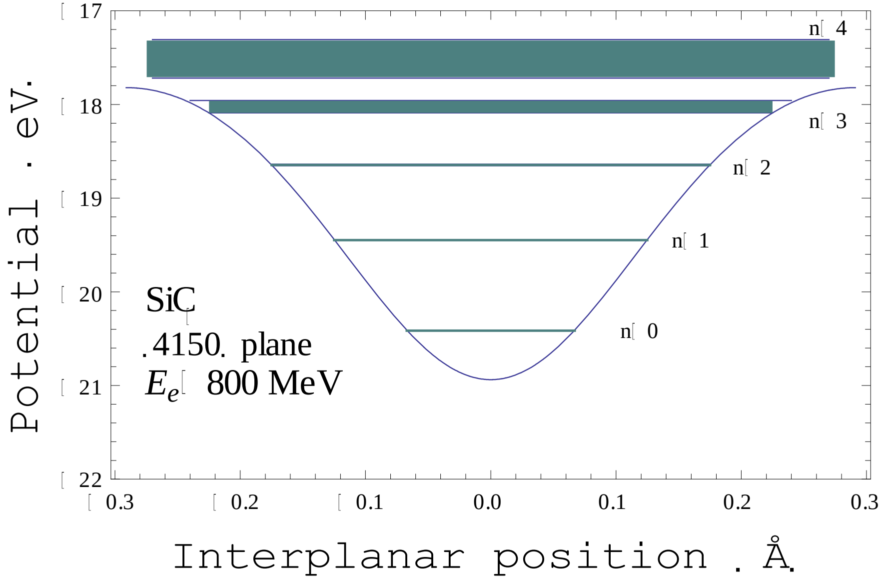
10^3.d .d d
Photon energy . MeV.
SiC
.1120. plane
E_e 200 MeV
0 0.0 mrad

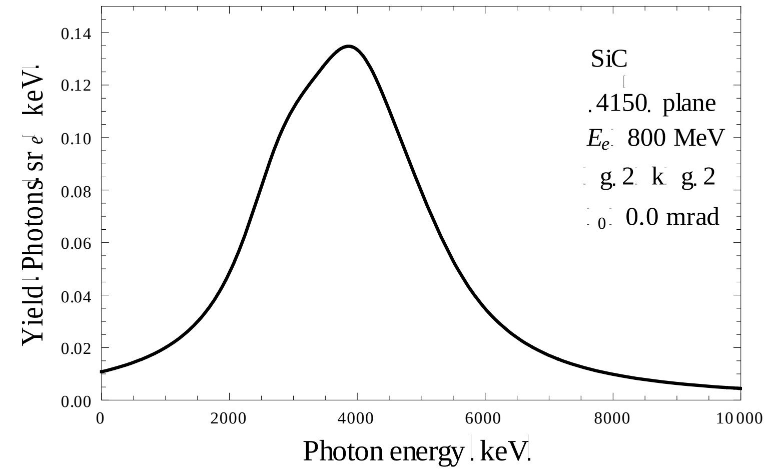


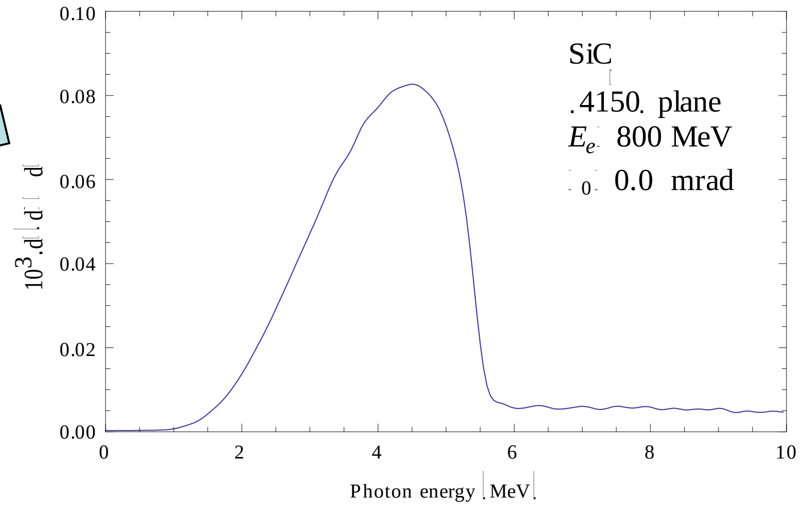




Which one is valid?







Which one is valid?

5. Summary

- Planar CR emitted by electrons channeled in diamond crystals has been investigated theoretically as well as experimentally.
  - CR energies, line widths and yields have been calculated implementing the many-beam formalism into a newly developed computer code.
  - Measurements of CR performed at ELBE are well interpreted.
  - The intense CR X-ray source recently installed at ELBE provides photon fluxes up to about 10^{11} s^{-1} at photon energies between 10 and 70 MeV within a bandwidth of 10 %.

- Generation of CR on quartz at medium electron energies has for the first time been carried out at ELBE and could be interpreted by corresponding calculations using real crystal potentials.
  - Measured data provide preconditions for the investigation of CR stimulated by ultrasound.

- Two theoretical approaches have been considered to study the influence of US on CR.
  - Changes of the spectral distribution of CR are predicted.

- First measurements of CR stimulated by US at non-resonant frequency have been performed at ELBE.
  - CR emission rates are diminished by the influence of non-resonant US.
  - Resonance frequencies are mostly larger than 10 GHz.
  - Further experiments are necessary to prove theoretical predictions.