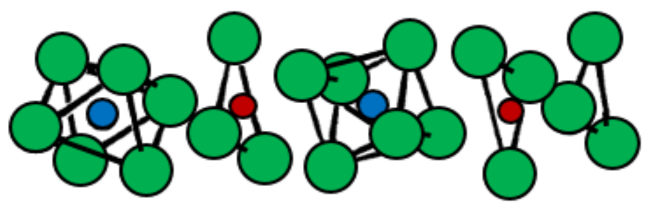
Investigations of Pyroelectric Crystals for Vacuum Electron Sources and X-ray Applications



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Motivation

- pyroelectric effect was already described twenty-three centuries ago
- not well explored
- used to generate X-rays for X-ray fluorescence analysis

Aim:

- better understanding of the pyroelectric effect
- X-rays of high intensities
- Material analysis (XRF)

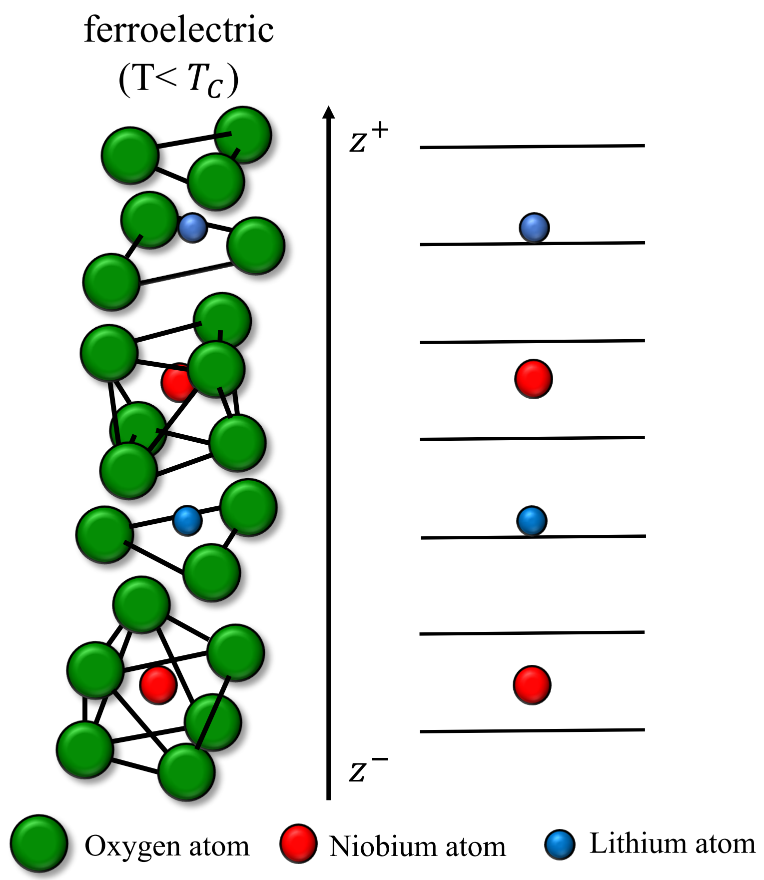
The Pyroelectric Effect

$$\Delta U = \frac{p \cdot z}{\varepsilon_r \cdot \varepsilon_0} \Delta T$$

- describes a spontaneous change of polarization as a result of changes in temperatur of the material

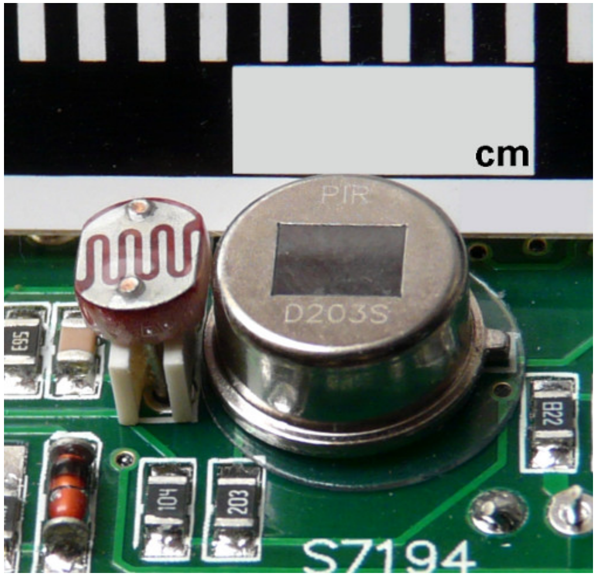
- external electrical field is build up by heating and cooling the crystal in vacuum

→ ionization of molecules and acceleration of electrons



Use of the Pyroelectric Effect

- different materials like lead zirconat titanate (PZT), barium titanate and lithium niobate
- pyroelectric infrared sensor (PIR-sensor) for:
  - infrared fire detectors
  - infrared motion detectors
- temperature sensor
- calorimeter



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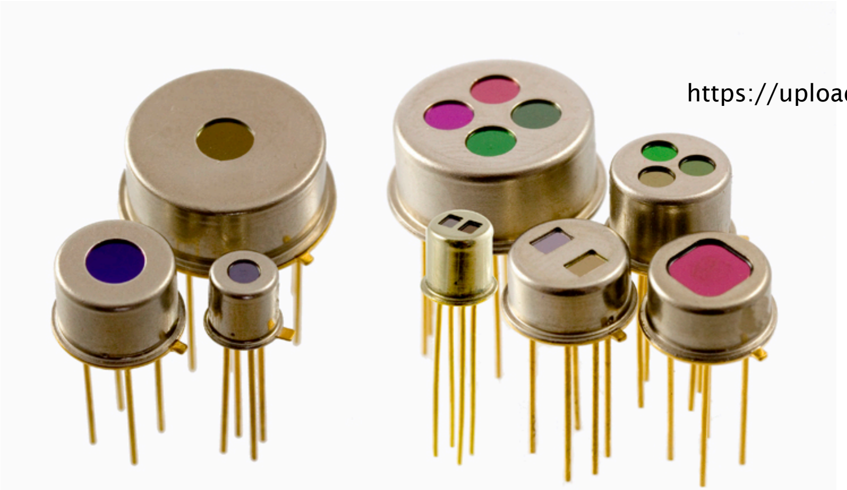
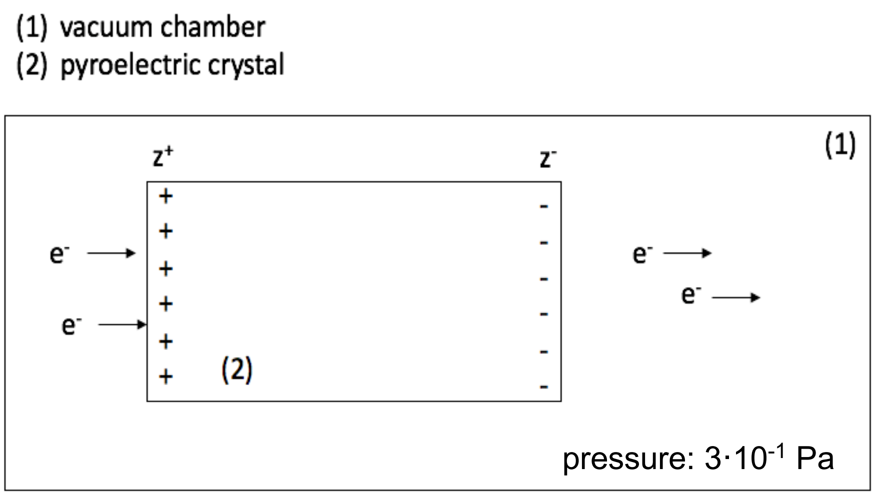
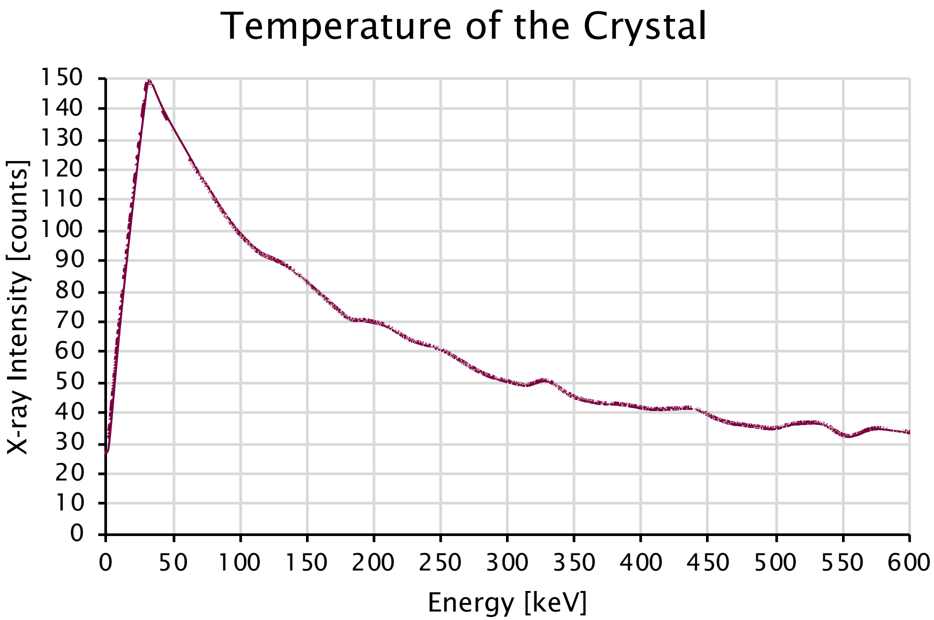


https://upload.wikimedia.org/wikipedia/commons/b/b9/Pyroelectric_detectors_from_InfraTec.jpg

Use of Pyroelectric Crystals in Electron Sources





- heating and cooling the crystal in a vacuum

  → strong electrical field (field strength up to 1.35×10^7 V/cm)

- ionization of residual gas molecules

  → emission and acceleration of electrons

Use of Pyroelectric Effect in X-ray Sources

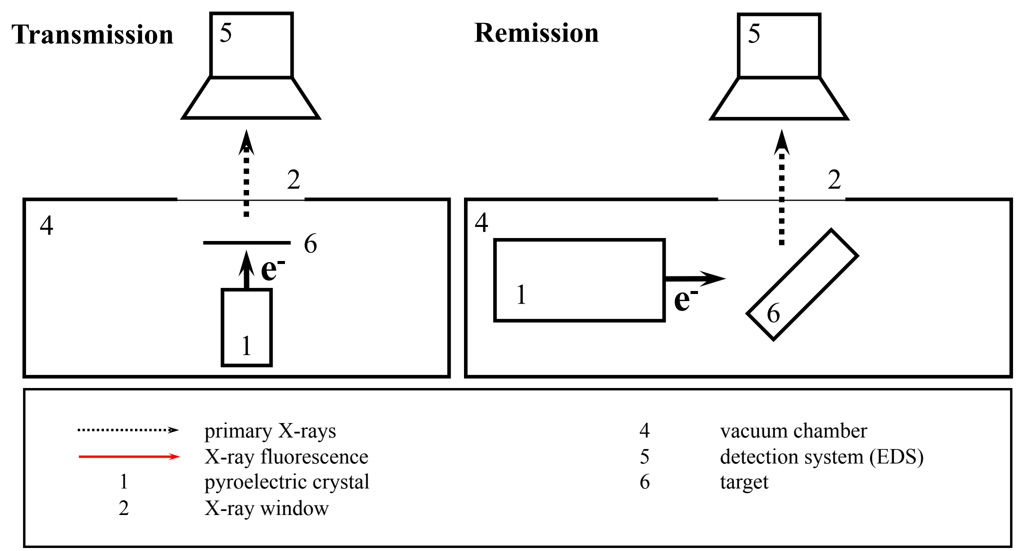
- acceleration of emitted electrons towards a target

  → interaction causes the emission of X-rays

- different arrangements between pyroelectric crystal and target

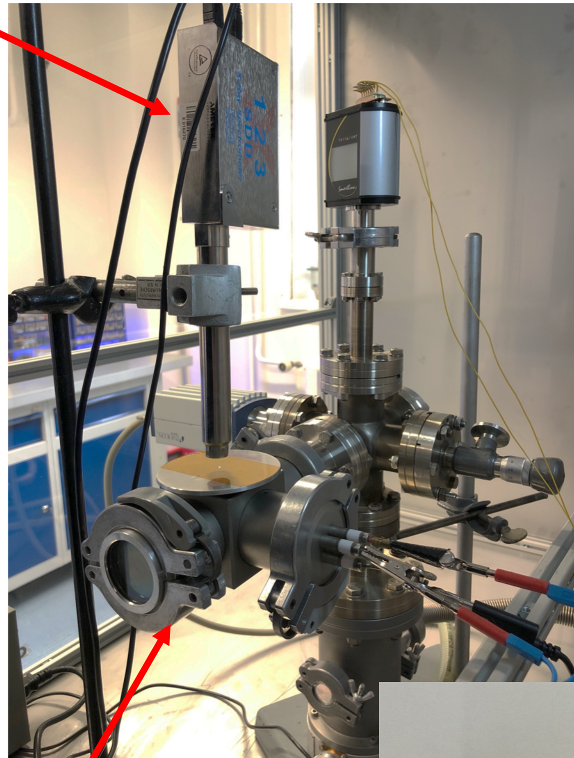
➢ emission of X-rays

with energies up to 160 keV

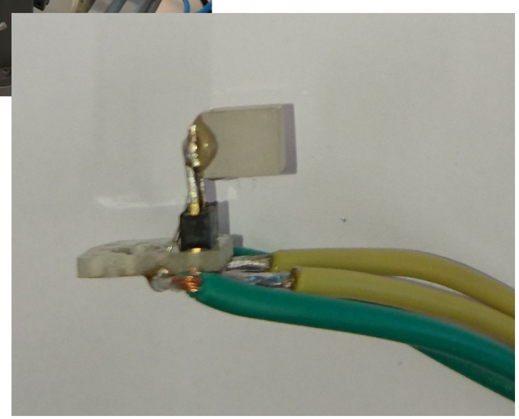


Experimental Setup

EDS-detector

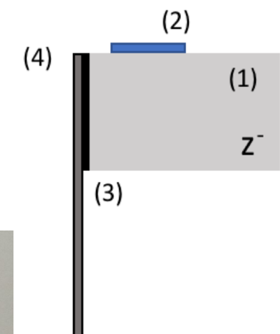


vacuum chamber with pyroelectric crystal



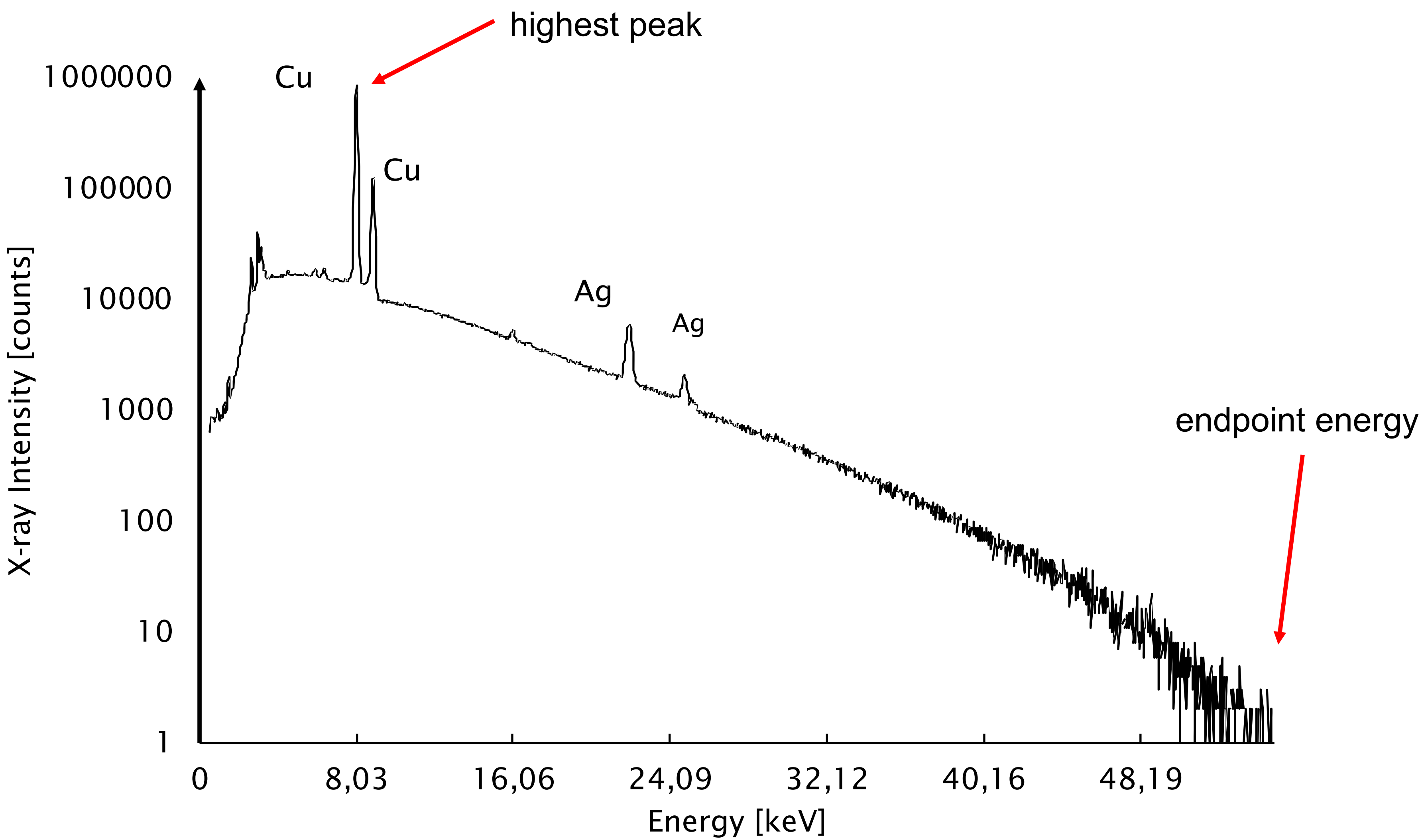
parameters:

- LiNbO3, LiTaO3 (x · y · z: 3 · 3 · 6 mm, 5 · 5 · 6 mm, 7 · 7 · 6 mm and 9 · 9 · 6 mm)
- resistance heating to 150°C, passive cooling
- 2 · E-1 to 5 · E-1 Pa
- spectra collection for 600 s



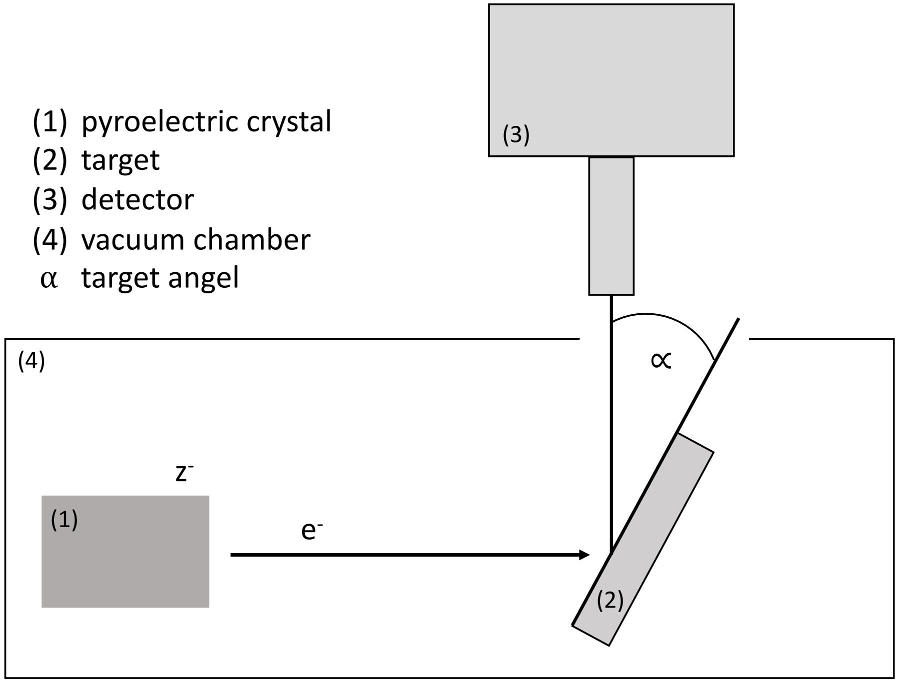
(1) pyroelectric crystal
(2) temperature sensor
(3) resistor
(4) plug

X-ray Spectra

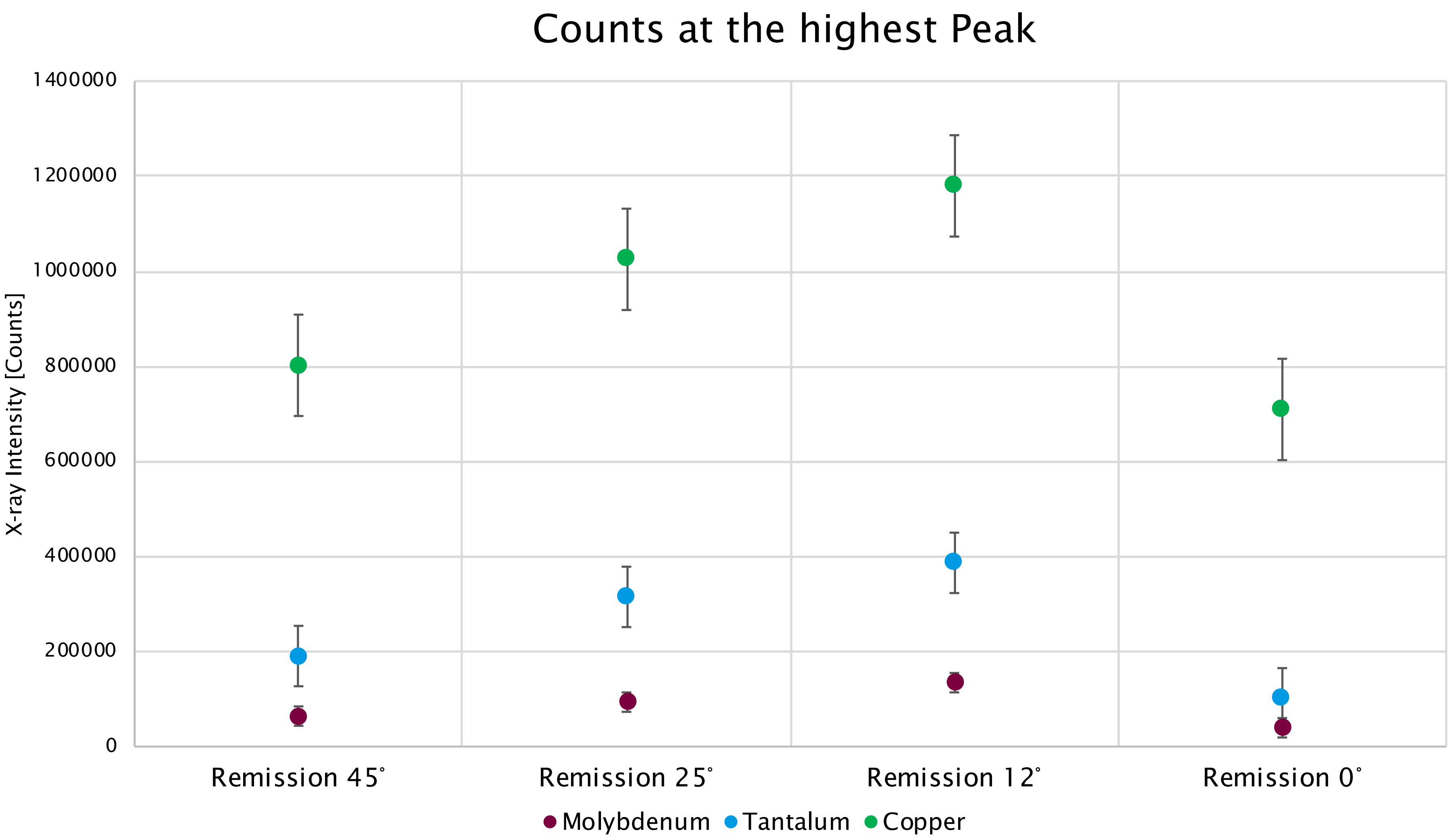


Influence of Different Target Angles on the Intensity

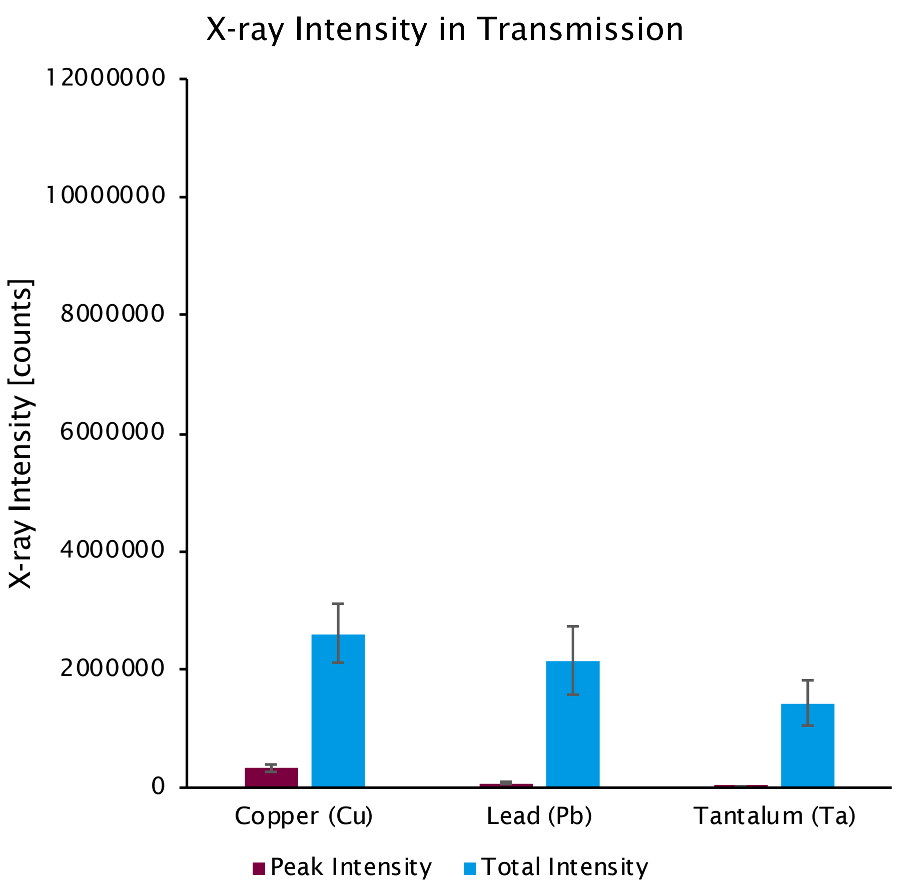
(1) pyroelectric crystal
(2) target
(3) detector
(4) vacuum chamber
α target angel

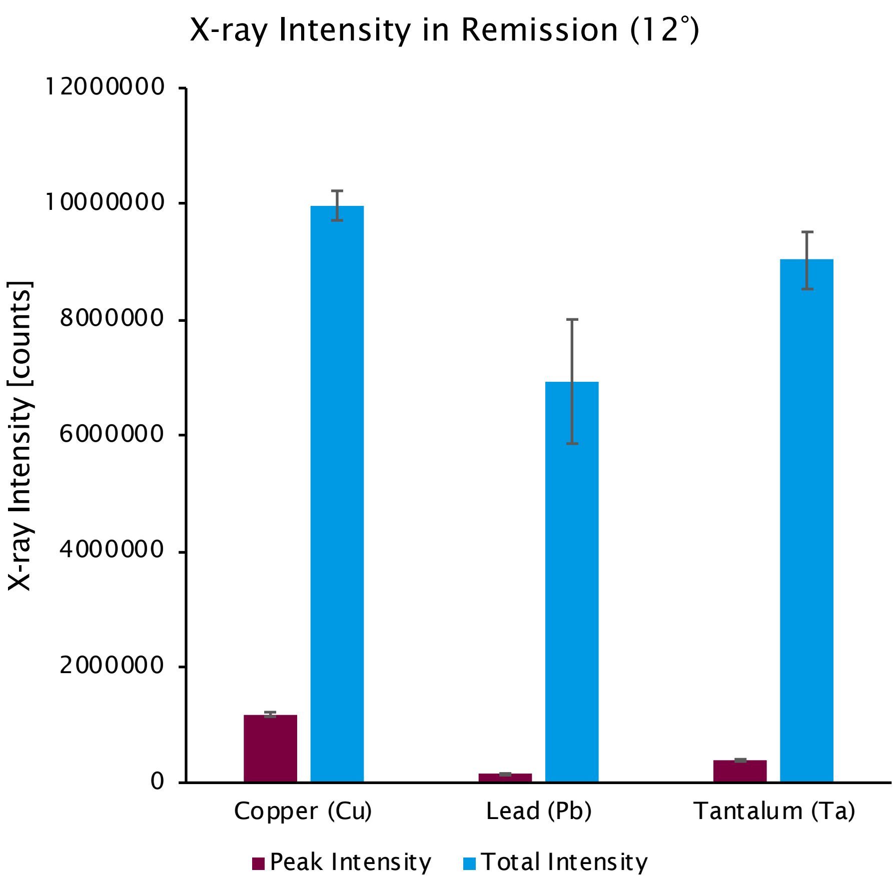


Influence of Different Target Angles on the Intensity

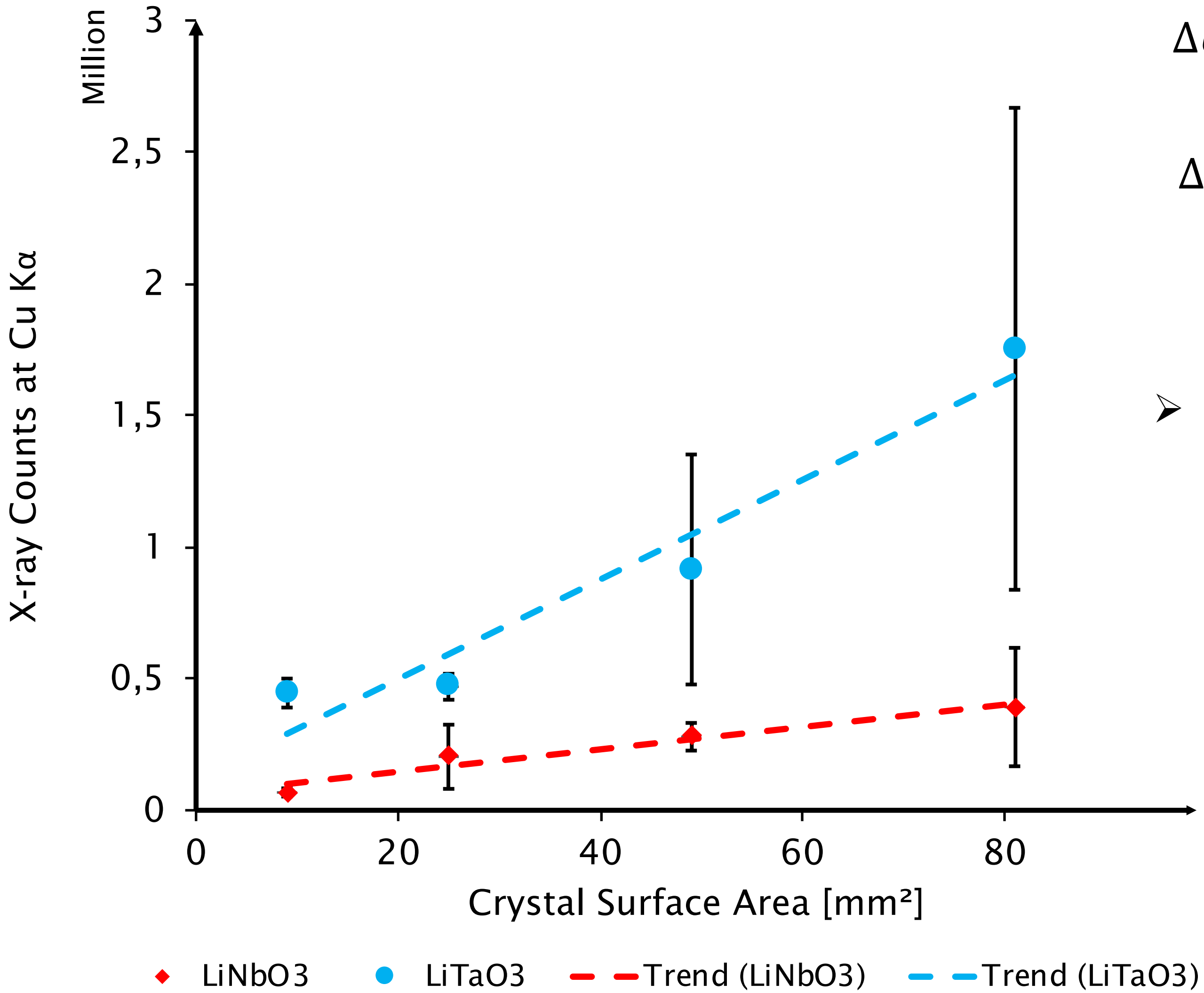


Comparison between Remission and Reflection Arrangement





Counts over Surface Area



$$\Delta U = \frac{p \cdot z}{\varepsilon_r \cdot \varepsilon_0} \Delta T$$

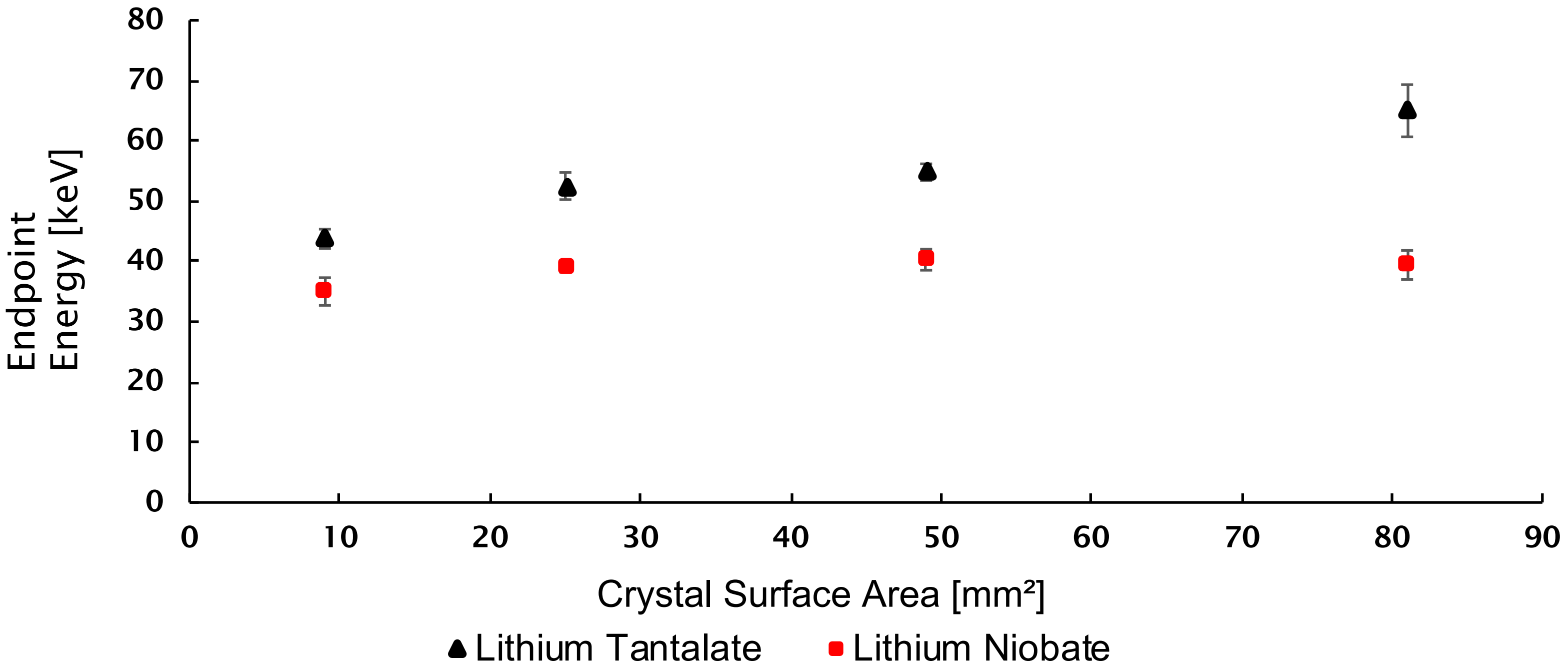
$$\Delta U_{\mathrm{LiTaO3}} \sim 1.3\, \Delta U_{\mathrm{LiNbO3}}$$

- Number of counts increases with bigger surface area

Influence of the Surface Area on the Intensity

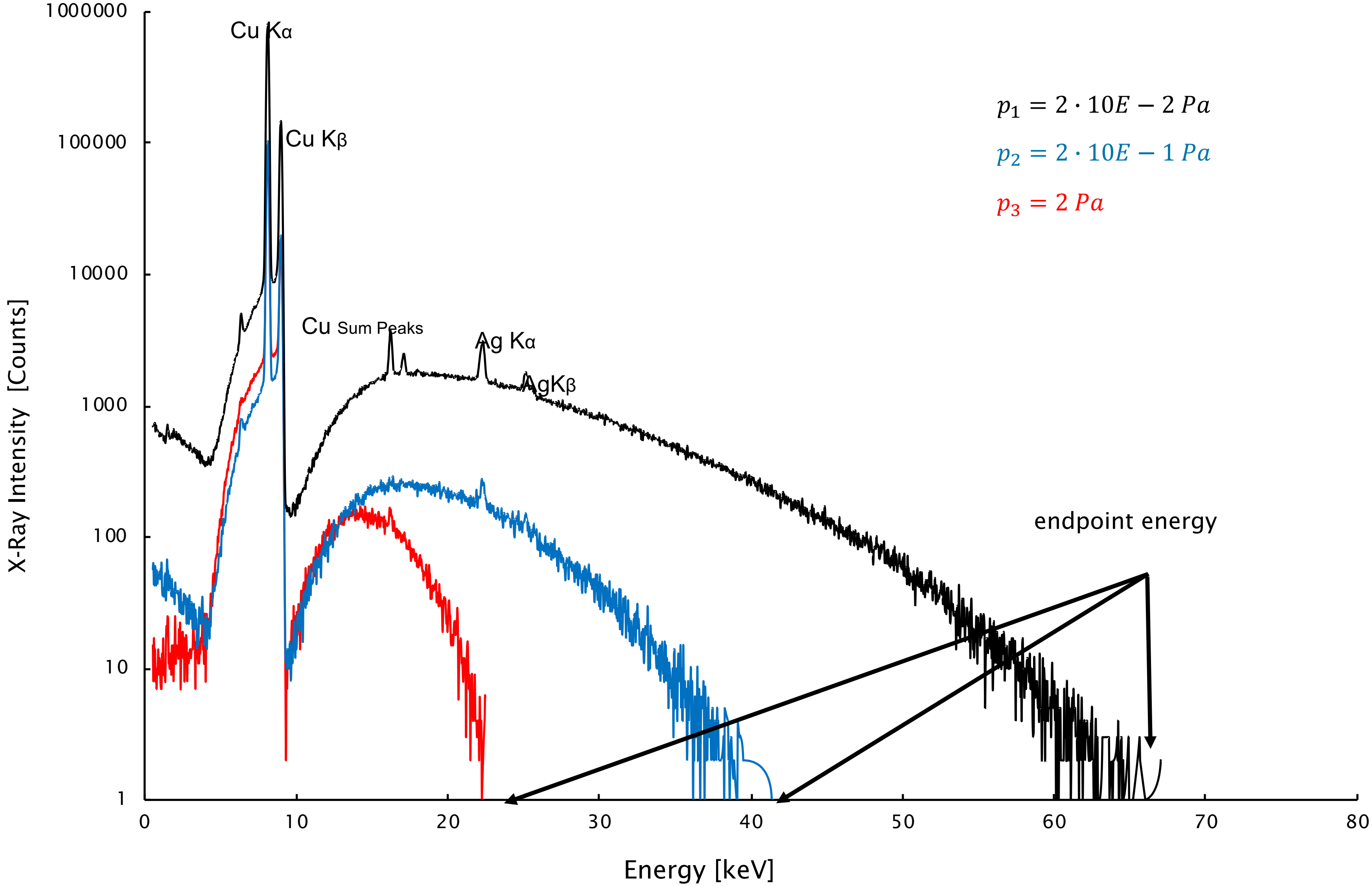
$$\Delta U = \frac{p \cdot z}{\varepsilon_r \cdot \varepsilon_0} \Delta T$$

$$\Delta U_{LiTaO3} \sim 1.3\ \Delta U_{LiNbO3}$$



- proportional correlation between endpoint energy and surface area of pyroelectric crystals

Influence of Pressure on the Endpoint Energy



The Pyroelectric X-ray Source “Cool-X“

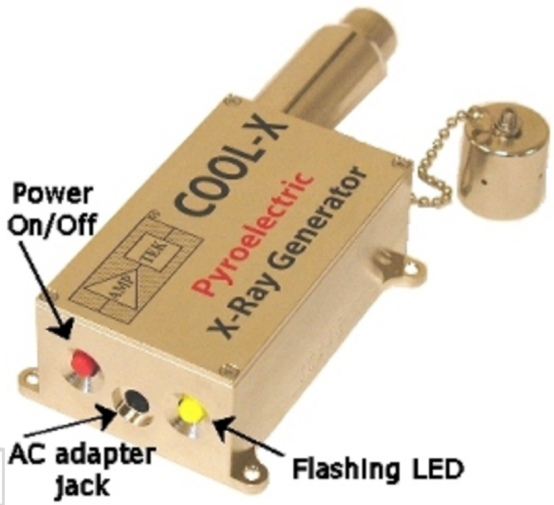
- a pyroelctric X-ray source is already available

<u>disadvantages:</u>

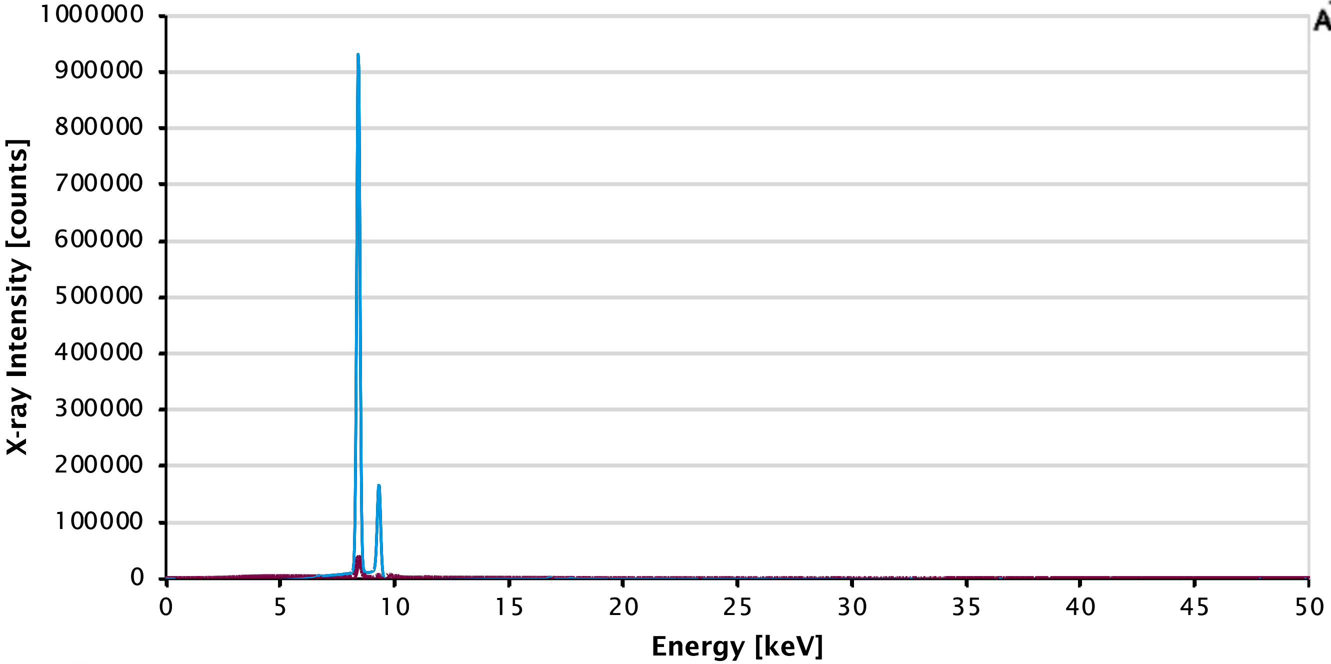
- low intensity

→ leads to long measuring time

→ short durability



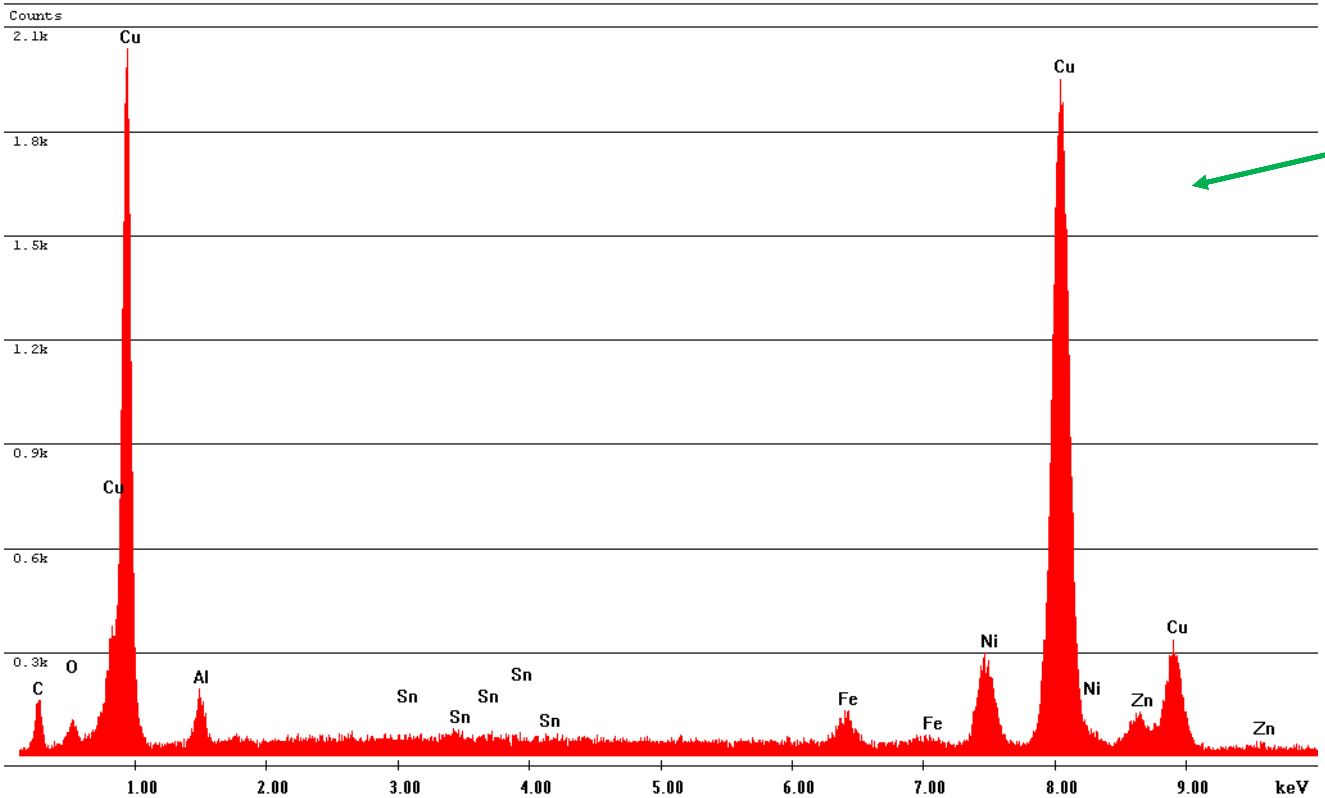
http://amptek.com/products/cool-x-pyroelectric-x-ray-generator/128/



XRF with a Pyroelectric X-ray Source

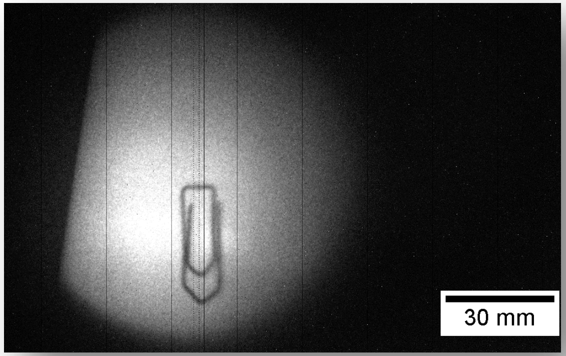
- X-rays with high intensity were used for XRF

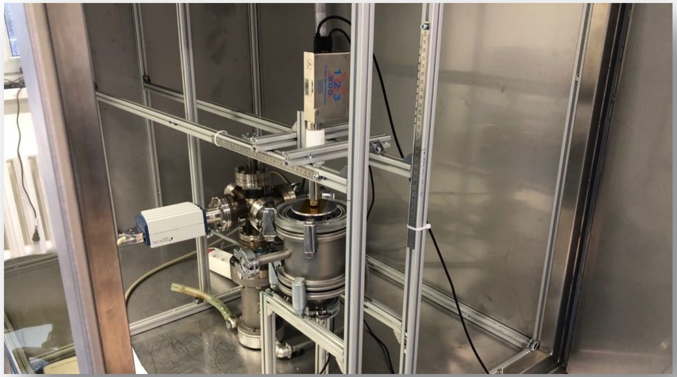
➢ qualitative and quantitative analyses within 60 seconds (cooling phase)

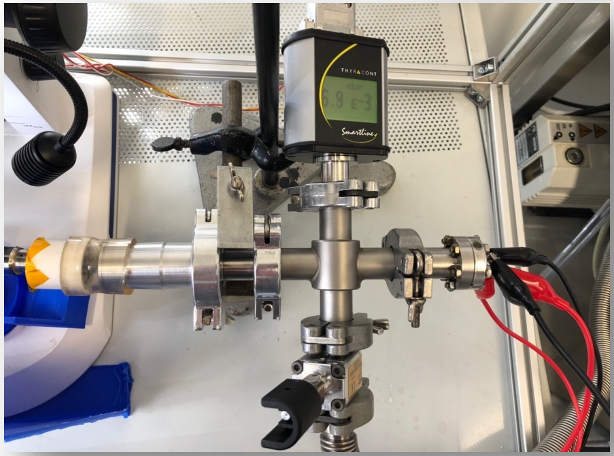


Conclusion

- influencing the emission of X-rays by various parameters (pressure, target angle, arrangement in general)
- high intensity X-rays were emitted
- possibility of material analyses (via XRF)







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Thank you for your attention!

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