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Sensors & Semiconductors Laboratory

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Silicon Undulator Prototype: manufacturing and X-ray Characterization

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Outline

- Why a crystalline undulator?
- Manufacturing techniques
  - The sandblasting method
  - The grooving method
- Conclusions

Classic free electron lasers

- Why a crystalline undulator?
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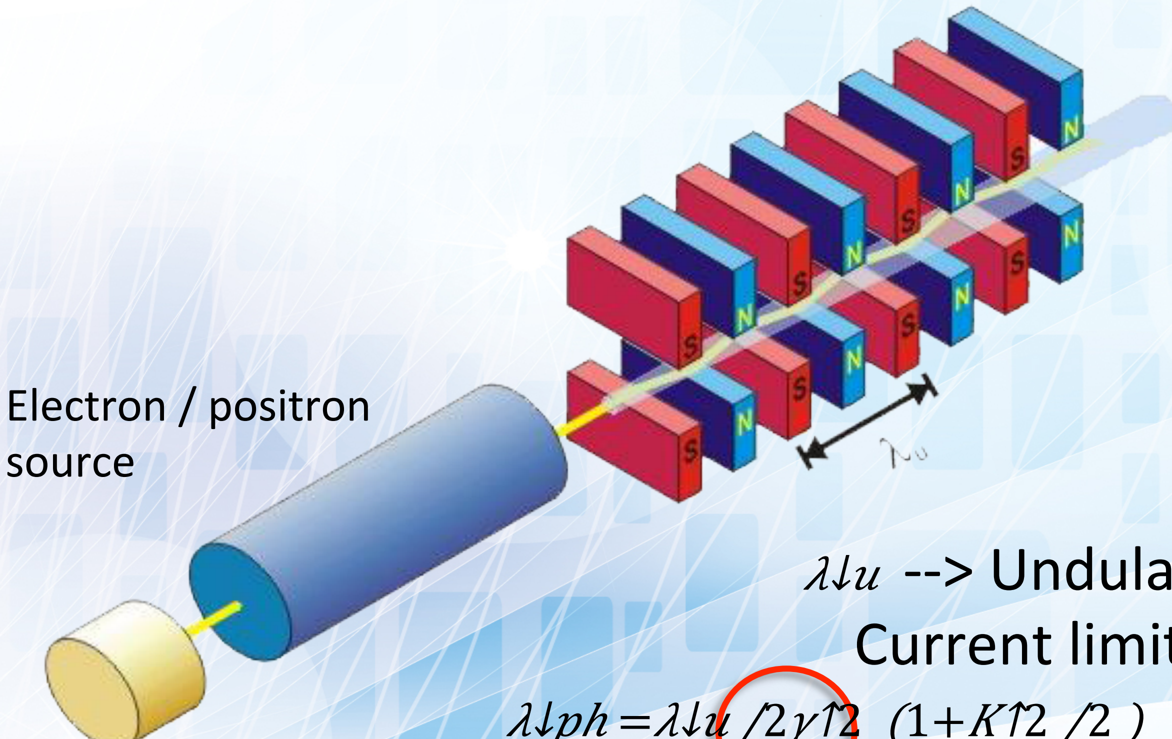
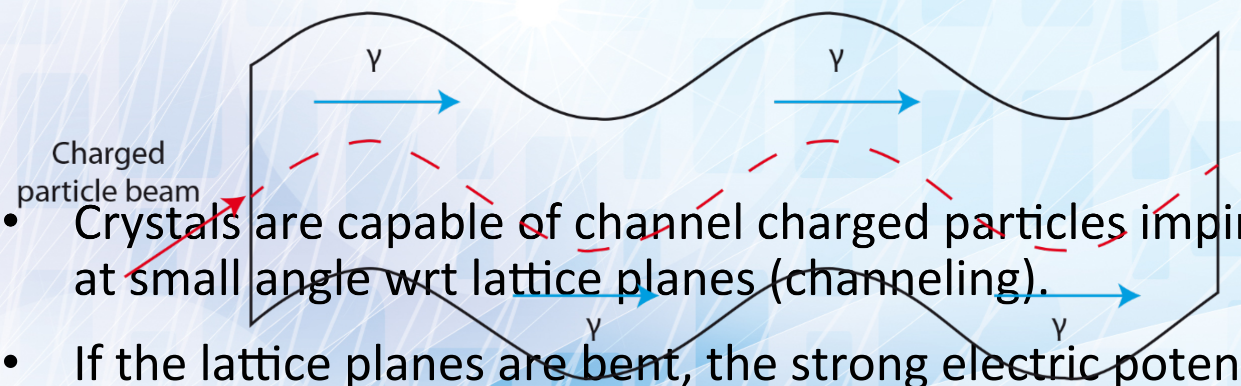


λ_u --> Undulation period

Current limit ~10 mm

$$\lambda_{ph} = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

Crystalline undulators



- Crystals are capable of channel charged particles impinging at small angle wrt lattice planes (channeling).
- If the lattice planes are bent, the strong electric potential induces channeled particles to follow the crystal curvature.
- A crystal periodically bent could induce a motion similar to a conventional magnetic undulator, with lower λ_u .

Manufacturing techniques

- We decided to manufacture CU made of silicon, because it is a material with a high crystalline order, easy to work.

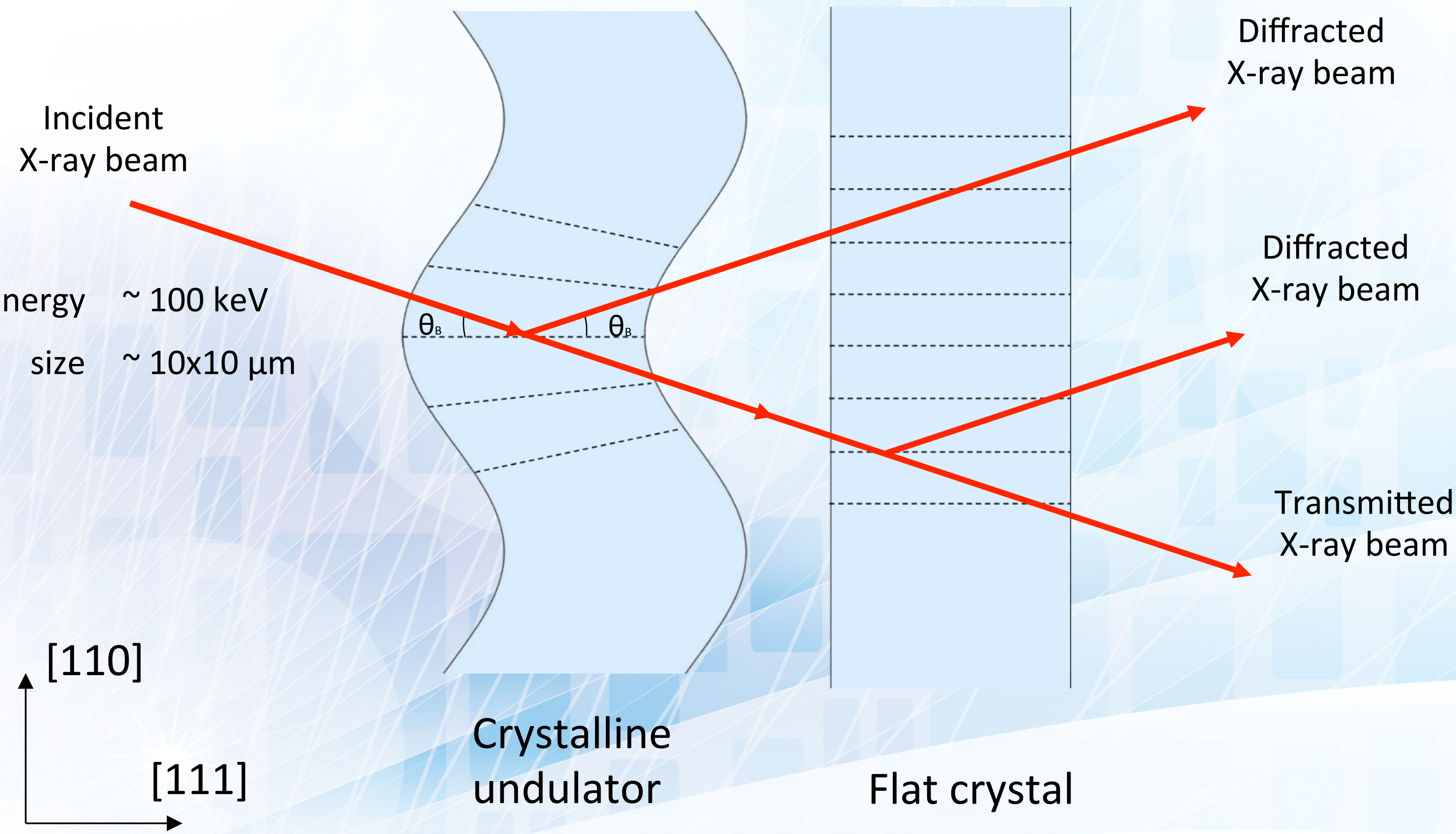
- Only mechanical techniques have been used, to study the possibilities of such methods. The deformation is self-standing.
- If only mechanical means are used, no contaminating elements are deposited on the CUs.

Hard X-ray measurement

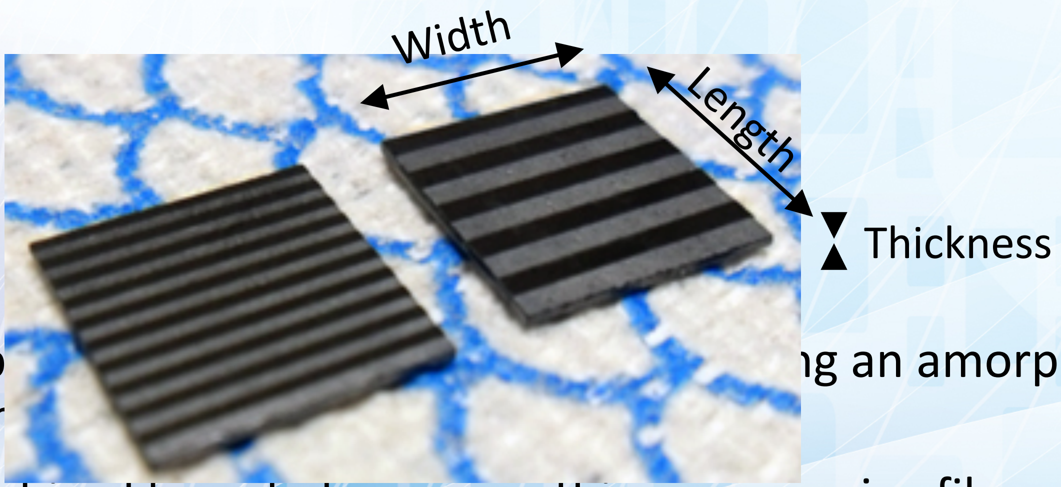
Measurements performed at ESRF and ILL (Grenoble, France)

energy ~ 100 keV

size ~ 10x10 µm



Sandblasting method



- The sandb… …ng an amorphized layer on th…
- The amorphized layer behaves as a thin compressive film, causing the curvature of the substrate.
- To obtain an undulated deformation, both faces must be patterned, with a phase shift of half a period.

Sandblasting method

Method	Sandblasting
Material	Silicon (111)
Thickness	1.0 mm
Length	8.0 mm
Width	10.0 mm
Period (λ_u)	2.0 mm
Number of periods	4
Amplitude	23 nm

Analysed through hard X-rays at the DIGRA facility, ILL, Grenoble (France)

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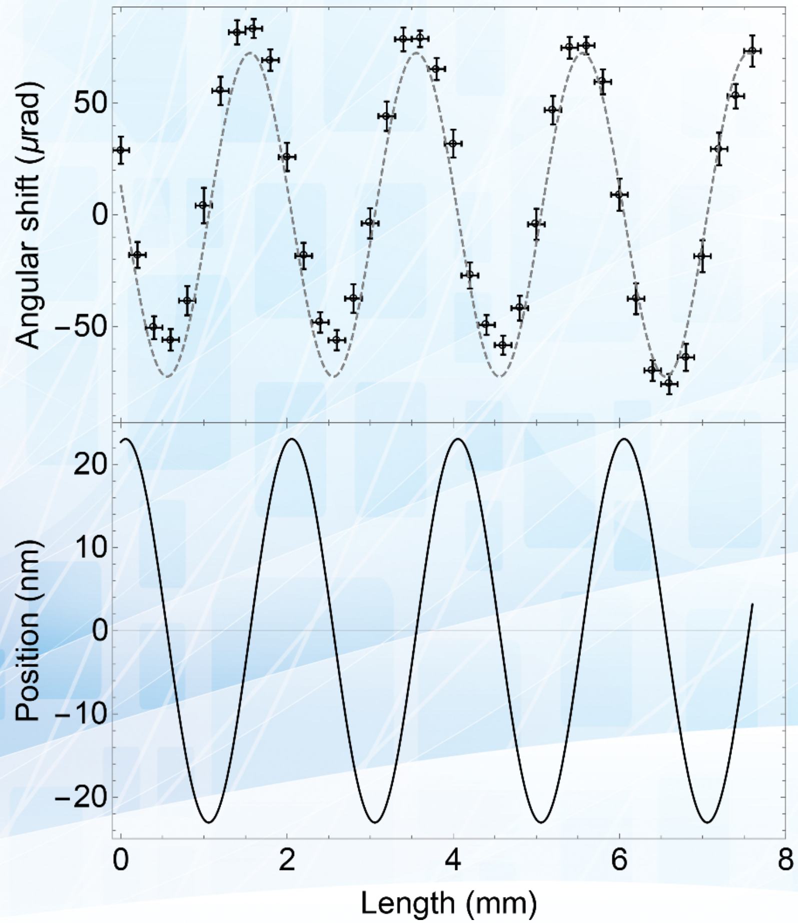


Camattari et al. J. Appl. Cryst. 50 (2017) 145-151

Sandblasting method

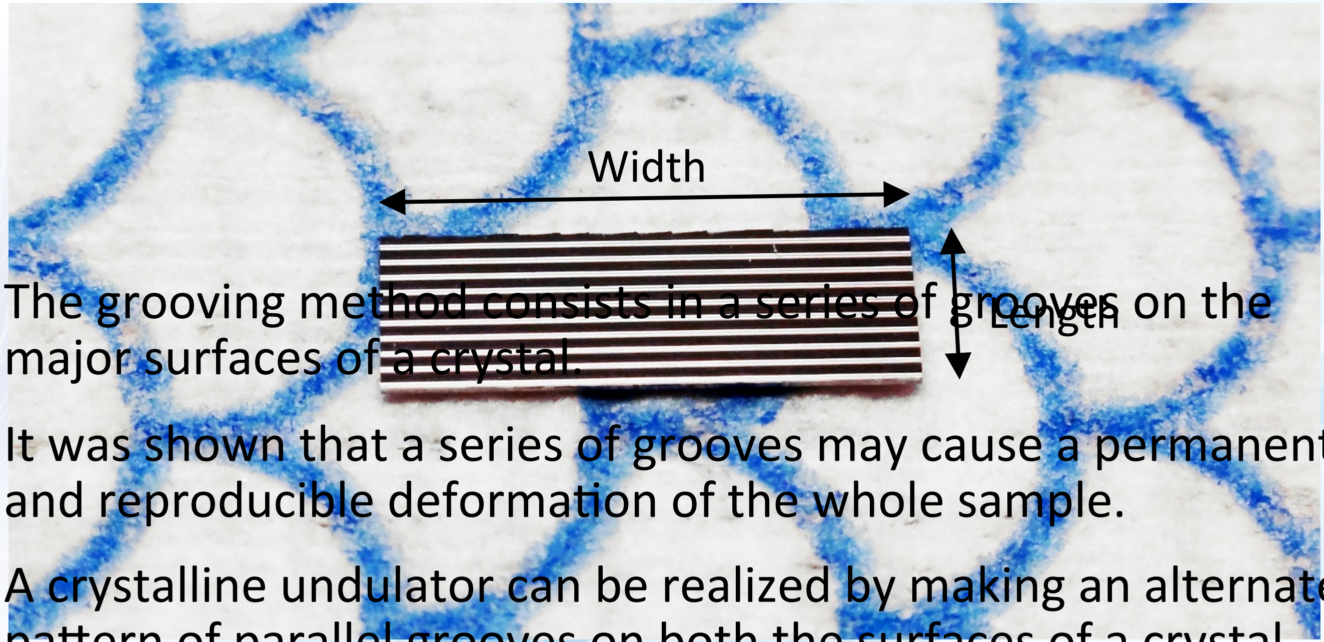
Advantages

- No Contaminants
- Adjustable
- Easy and economic
- Fast

Disadvantages

- Crystal damage
- The period (λ_u) is limited to be not smaller than ~ 1 mm

Grooving method



- The grooving method consists in a series of grooves on the major surfaces of a crystal.
- It was shown that a series of grooves may cause a permanent and reproducible deformation of the whole sample.
- A crystalline undulator can be realized by making an alternate pattern of parallel grooves on both the surfaces of a crystal, with a phase shift of half a period.

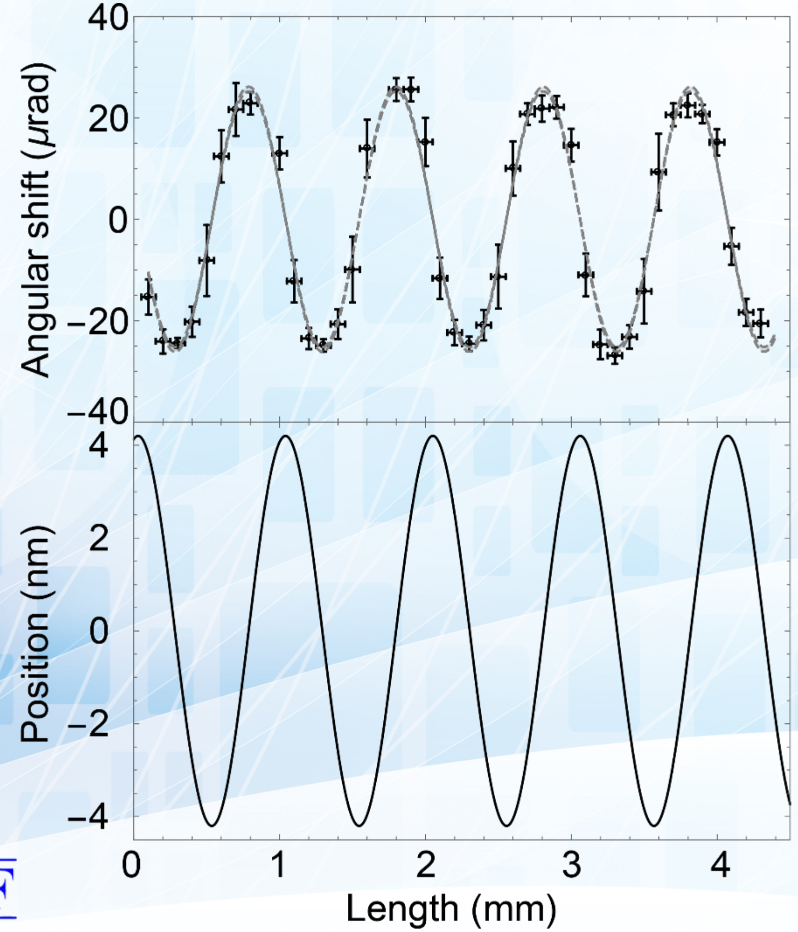
Camattari et al Meccanica 48 (2013) 1875-1882

Grooving method

Method	Grooving
Material	Silicon (111)
Thickness	0.2 mm
Length	5.0 mm
Width	45.0 mm
Period (λ_u)	1.0 mm
Number of periods	5
Amplitude	4.1 nm

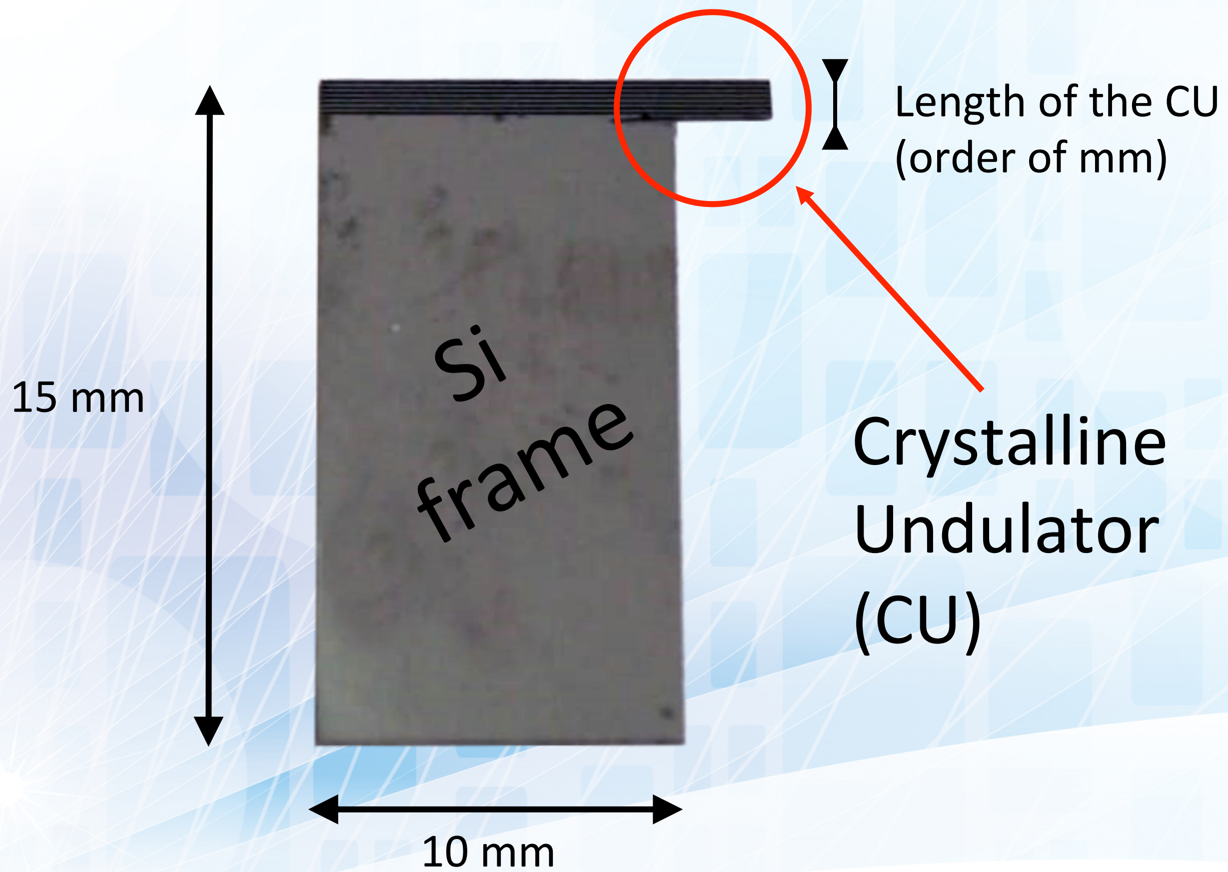
Analysed through hard X-rays at the ID15 facility, ESRF, Grenoble (France)

ESRF



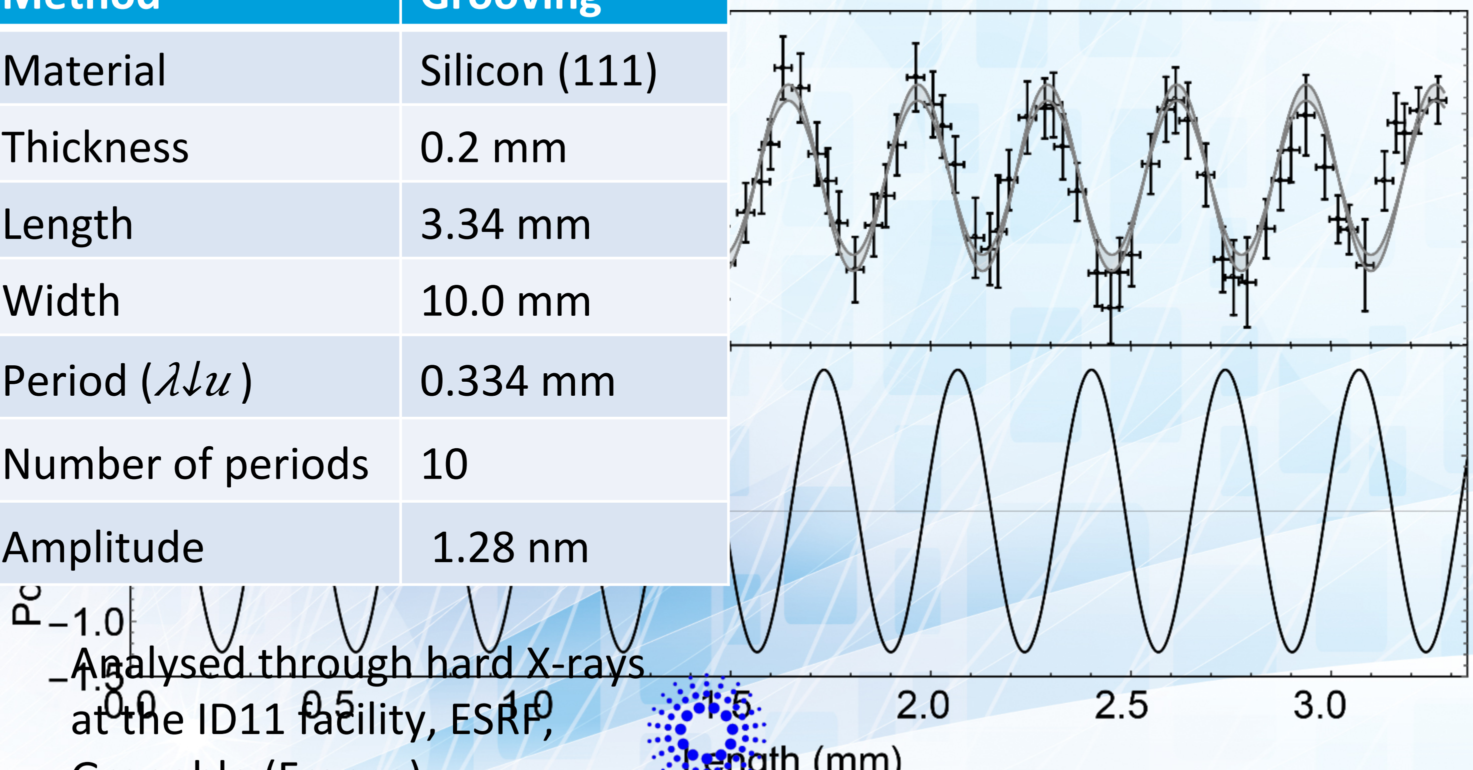
Bagli et al. Eur. Phys. J. C 74 (2014) 3114

Grooving method



Grooving method

Method	Grooving
Material	Silicon (111)
Thickness	0.2 mm
Length	3.34 mm
Width	10.0 mm
Period (λ_u)	0.334 mm
Number of periods	10
Amplitude	1.28 nm



Analysed through hard X-rays at the ID11 facility, ESRF, Grenoble (France)

ESRF

Prelaminar results

Grooving method

Why a crystalline undulator?

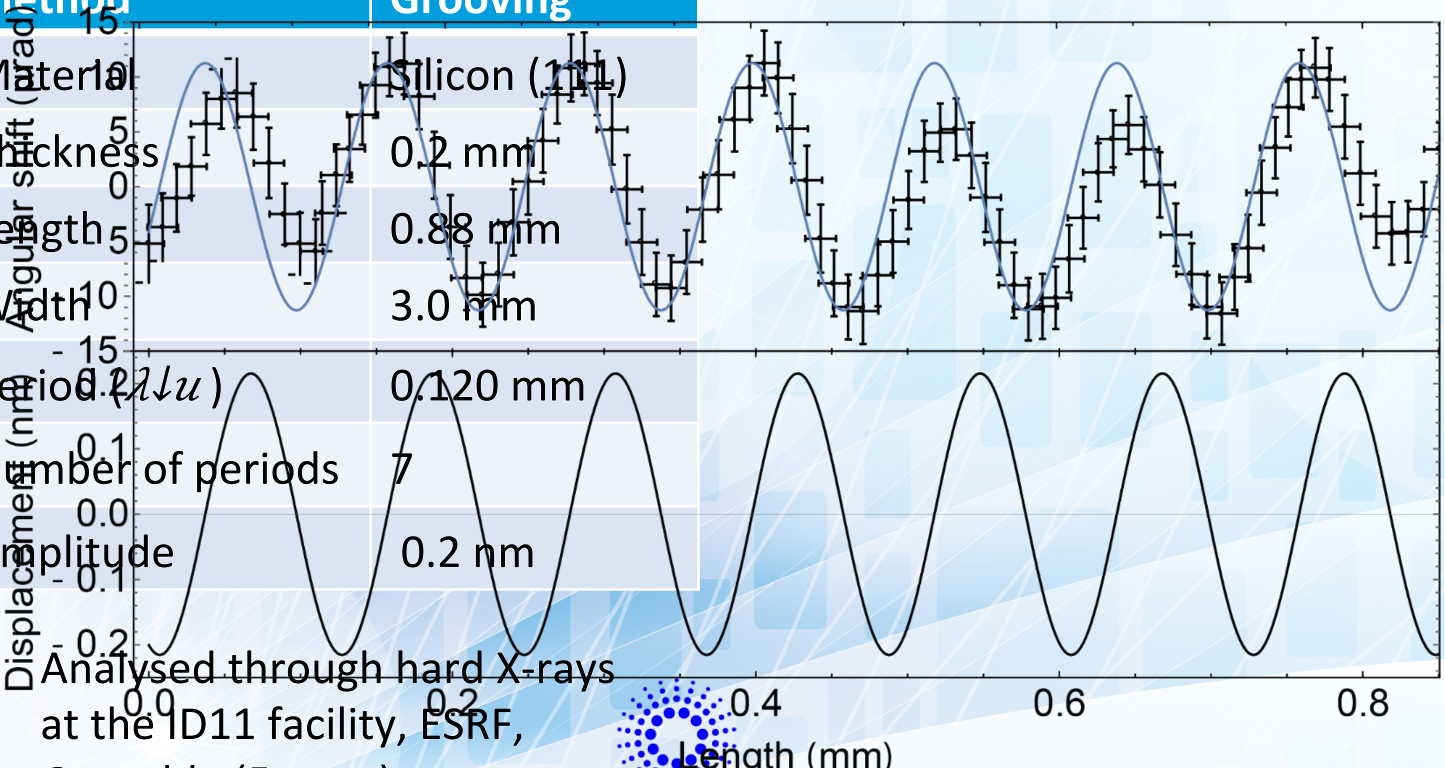
Manufacturing techniques

The sandblasting method

The grooving method

Conclusions

Method	Grooving
Material	Silicon (111)
Thickness	0.2 mm
Length	0.88 mm
Width	3.0 mm
Period (λ_u)	0.120 mm
Number of periods	7
Amplitude	0.2 nm



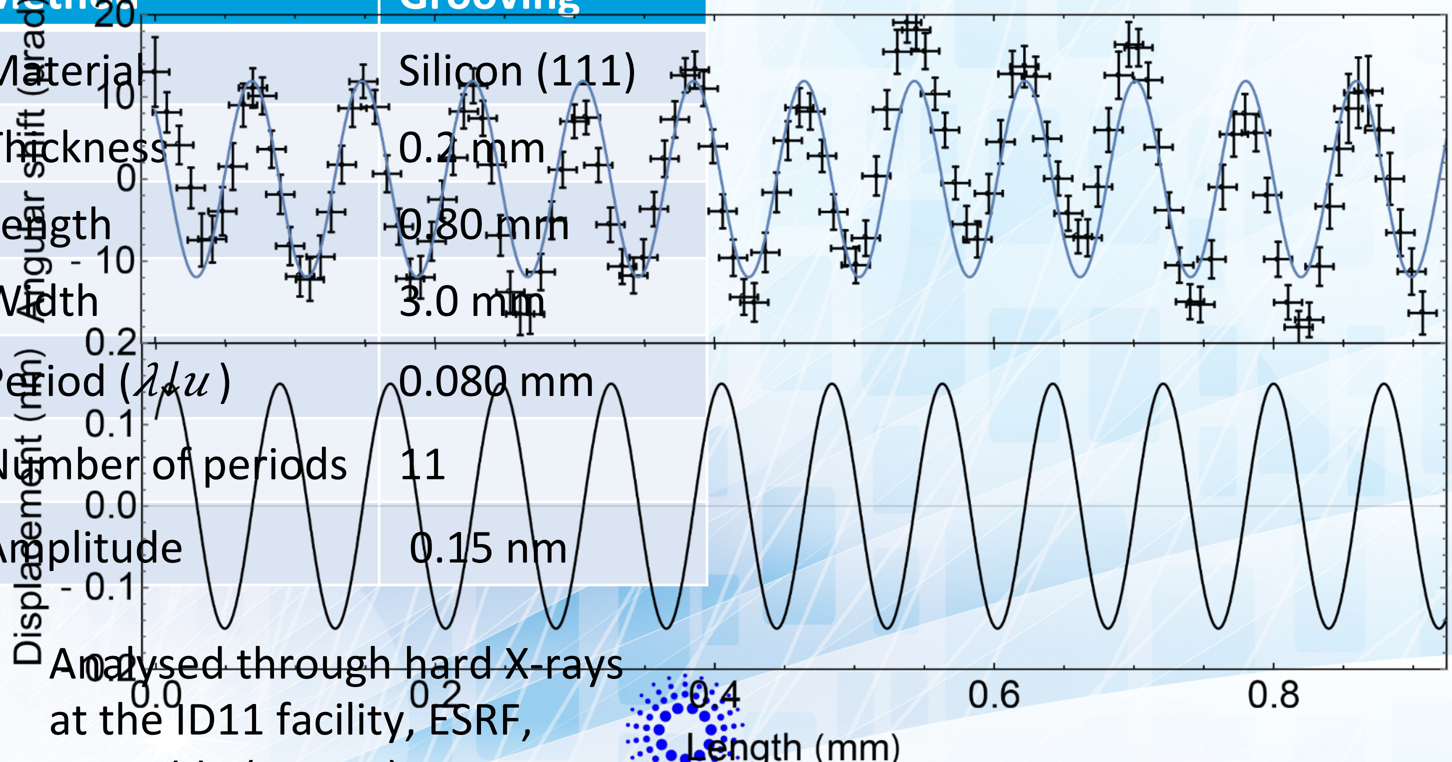
Analysed through hard X-rays at the ID11 facility, ESRF, Grenoble (France)

ESRF

Prelaminar results

Grooving method

Method	Grooving
Material	Silicon (111)
Thickness	0.2 mm
Length	0.80 mm
Width	3.0 mm
Period (λ_u)	0.080 mm
Number of periods	11
Amplitude	0.15 nm



Analysed through hard X-rays at the ID11 facility, ESRF, Grenoble (France)

ESRF

Prelaminar results

Grooving method

Advantages

- No Contaminants
- Adjustable
- The period can be as small as the blade width

Disadvantages

- Crystal damage

Method comparison

Sandblasting method		Grooving method	
No contaminants	↑	No contaminants	↑
Adjustable	↑	Adjustable	↑
Higher period	↓	Smaller period	↑
Less crystal damage	↑	More crystal damage	↓

Conclusions

- Self-standing undulated crystals have been realized.
- It is possible to decrease the period, but it decreases also the undulating amplitude.
- The smallest period was obtained with the grooving method, namely 80 µm with 0.15 nm of amplitude.
- Test with charged particles are fundamental for evaluating the crystal damage.

Thank you for your attention