concept for a reflectometer for the ESS with focusing in sample and scattering plane

Workshop on off-specular neutron scattering
09.–10. 01. 2012, Bruxelles, Belgium
slit optics vs. focusing optics

small samples

focusing with elliptic guides
  • coma aberration
  • operation modes

realisation
  add-on for Amor $\rightarrow$ experimental results
  2D prototype for BOA
  concept for the ESS

3D reflectometry
  $R(q_z, q_x)$ (conventional)
  $R(q_z, y)$ (scan of the sample surface)
  parallel beam (for GISANS)
  spin-echo type add-ons / spatial constraints
slit vs. focusing optics
slit vs. focusing optics

focusing via

slits

reflective / refractive optics

penumbra
umbra

beam profile
slit vs. focusing optics

dimensions are freely scaleable

⇒ adjustable to
  - TOF length
  - sample environment
  - spin-echo spatial needs
  - available space
  - ...

slit vs. focusing optics

focusing for high-flux specular reflectometry

slit-defined beam:
- \( \theta \)-dispersive, or
- \( \lambda \)-dispersive,
- resolution given by \( \Delta \lambda \) and \( \Delta \theta \)

convergent beam:
- \( \theta \)-dispersive and
- \( \lambda \)-dispersive,
- resolution given by \( \Delta \lambda \) and detector
slit vs. focusing optics

focusing for high-flux specular reflectometry

slit-defined beam:

convergent beam:

elliptic reflector

≡ converging lense

slit vs. focusing optics

focusing for high-flux specular reflectometry

slit-defined beam:

convergent beam:

TOF operation
small samples
**small samples**

i.e. **samples smaller than the beam**

e.g.  
- PLD-grown samples
- latterally structured films
- functional devices
- samples compatible with x-ray or magnetometry environments

projected height $< 1$ mm!

Ni/Ti multilayer on Si, $4 \times 3$ mm$^2$

perovskite multilayer on STO, $5 \times 5$ mm$^2$
**small samples**

i.e. **illumination of a defined area, only**

- inner region within a trough
- inner region of a solid-liquid cell:
  - samples with electrical contacts
  - partially coated substrates
  - bent substrates

footprint \(<\) substrate  

```
typical dimensions: 10 \times 10 \text{mm}^2 \text{ to } 20 \times 40 \text{mm}^2
```  

i.e. **latteraly inhomogeneous samples**

- structured materials
- samples with (large) domains

footprint \(\ll\) substrate  

```
typical dimensions: 0.1 \times 10 \text{mm}^2
```  

⇒ **scanning of sample area**
focusing with elliptic guides

real focusing!
⇒ pre-image → image

no fancy version of a ballistic guide!
focusing with elliptic guides

generic instrument layout

cut in the scattering plane
stretched by 10 normal to incident beam

initial slit $\equiv$ projected sample size (e.g. $5 \times 1$ mm$^2$)

intermediate image: beam manipulation
- polarising reflector
  - small chopper
  - deflector (to bend beam)

$1^{st}$ elliptic reflector
no direct line of sight

knife blade
$2^{nd}$ elliptic reflector
corrects for coma aberration

sample
detector
**focusing with elliptic guides**

why only one branch of an ellipse?
– no structured $I(\theta, z)$
– one branch can cover $\Delta \theta$

why two subsequent elliptic guides?
– convenient beam manipulation
– guide dimensions not too large
→ correction for coma aberration!
focusing with elliptic guides

coma aberration — and its correction

\[ a = 2000 \text{ mm} \]
\[ b = 40 \text{ mm} \]
focusing with elliptic guides

coma aberration — and its correction

limitations:
– finite length of the guides
– non-perfect coating

opportunities:
– use aberration to reduce beam spot or divergence at the sample
focusing with elliptic guides

operation modes for TOF:

(non-TOF operation is also possible!)
focusing with elliptic guides

mode: almost conventional

– beam is still convergent
– off-specular measurements are feasible
focusing with elliptic guides

mode: wide $q$-range

- vary $\theta$ with fixed sample position
- shift diaphragm (chopper) between pulses

- suited for liquid surfaces
**focusing with elliptic guides**

**mode: small spot size**

- uses focusing due to coma aberration
- **scanning mode possible**

use coma aberration to reduce beam size
**focusing with elliptic guides**

**mode: small spot size**

- uses focusing due to coma aberration
- **scanning mode possible**

\[ I(y, z) \text{ and } I(z, \theta_z) \text{ at the sample} \]

for a 1 \times 1 \text{mm}^2 entrance slit

use coma aberration to reduce beam size
focusing with elliptic guides

mode: low-divergent beam

- uses defocusing due to coma aberration
- corresponds to the use of Montel optics used at synchrotrons
- for high $q_z$ resolution

- parallel beam e.g. for GISANS

use coma aberration to reduce divergence
focusing with elliptic guides

mode: angle/energy encoding

– use a ml-monochromator at the intermediate image
– spectral analysis of the beam: $\lambda / \theta$ encoding

– large $\lambda$ on small $\theta$
  $\Rightarrow$ wide $q_z$-range

$I(\lambda, \theta)$ after ml monochromator
focusing with elliptic guides

mode: high-intensity specular reflectivity

- energy- and angle-dispersive ⇒ gain > 10
- for fast scanning (T, H, E . . .)
- or if off-specular scattering is no problem
focusing with elliptic guides

high-intensity specular reflectivity vs. almost conventional
realisation

add-on for Amor

prototype on BOA

concept for the ESS
realisation: add-on for Amor

one guide element, only vertical scattering plane

detector

sample

elliptic guide

slit (with ml-monochromator)

end of guide
realisation: add-on for Amor

Amor, conventional TOF set-up

8 m granite block

maximum length chopper to detector = 10 m

$2\theta \in [-3^\circ, 12^\circ]$

$\lambda \in [2 \text{ Å}, 18 \text{ Å}]$

vertical scattering plane

detectors: $^3\text{He}$ single and area (180 × 180 mm$^2$)
realisation: add-on for Amor

- chopper housing
- 1st slit
- elliptic reflector (SwissNeutronics)
- sample (hidden by diaphragm)
- detector

guide slit focusing guide

chopper

knife-edge collimator

sample

detector

x/mm

-622 0 880 1880 3880 4880 8663
realisation: add-on for Amor

measurements: 1000 Å Ni film on glass, 9 × 9 mm²
realisation: add-on for Amor

measurements: 1000 Å Ni film on glass, 9 × 9 mm²

4 guide elements à 500 mm
realisation: add-on for Amor

measurements: 1000 Å Ni film on glass, 9 x 9 mm²

![Graph showing measured data and comparison between conventional and Selene set-ups.](image)

measurement time:

- **conventional**: 5 h
- **Selene**: 45 min

gain-factor: 6.7
realisation: add-on for Amor

\[ \text{[La}_{2/3}\text{Sr}_{1/3}\text{MnO}_3/ \text{SrTiO}_3]_4/ \text{NGO} \]

- no focusing in sample plane
- TOF mode, \( \lambda \in [2 \ldots 18 \, \text{Å}] \)
- measurement time:
  \begin{align*}
  \text{conventional} & \quad 6.5 \, \text{h} \\
  \text{Selene} & \quad 45 \, \text{min} \\
  \text{gain-factor} & \quad 8.3
  \end{align*}

by courtesy of C. Aruta and F. Miletto
realisation: add-on for Amor

$\log_{10}[I(\lambda, \theta)]$ maps taken with the liquid/solid interface cell with Si vs. D$_2$O.

$\Delta \theta = 1.1^\circ$

$\Delta \theta = 0.11^\circ$

$\omega = -0.7^\circ$

$\omega = 0.3^\circ$
realisation: prototype on BOA

Boa is a test beam line at SINQ, PSI

guide-end (40 × 150 mm², $\Delta \theta_y = 1.4^\circ$, $\Delta \theta_z = 2.0^\circ$)

chopper (Ø = 150 mm)

slit

elliptic guides

sample position

area detector

total length $\approx 8.6$ m

$\lambda \in [1.5, 12]$ Å

polarised beam

setup operational 8. 2012

$x/y$ translation, $2\theta/\omega$ rotation stages
realisation: concept for the ESS

schematic lay-out of the reflectometer for tiny samples
realisation: concept for the ESS

\[
\Delta \lambda \Rightarrow \text{total length}
\]

repetition rate multiplication chopper \(\Rightarrow \Delta \lambda / \lambda \approx 1\%\)

ml-monochromator \(\Rightarrow \Delta q_z / q_z \approx 5\% \ldots 20\%\)

\(\Delta \theta, \lambda - \text{range} \Rightarrow q_z - \text{range}\)
final remarks

critical points

thanks

Selene
critical points

- accuracy of guides
  - how to assemble the 0.5 m units without errors

- alignment of guides

- scattering at focal points
  - from diaphragms / choppers
  - off-specular form mirrors

  first simulation with off-specular scattering with McStas (K. Leffman, 12. 2011)

- influence of gravity
  - will be simulated within the next months
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Selene is a guide concept which . . .

- prevents direct line of sight
  - reduces radiation in the guide
  - allows for convenient beam manipulation
- reduces illumination of the sample environment
  - allows for a convergent beam set-up ⇒ flux gain > 10