Neutron optics in cryogenic sample environment

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Abstract. Neutron focusing devices can be used to enhance neutron instruments when measuring small samples. However, for an optimum performance they need to be as close as possible to the sample which, in most situations, conflicts with the need for sample environment such as pressure cells, cryostats or magnets. In this paper we explore the potential and feasibility to incorporate a neutron lens based on supermirror technology into a cryostat containing a Paris-Edinburgh pressure cell. We present experimental results on the performance of super-mirrors between 5 and 300 K. Based on the experimental results we estimate the expected gain factors for a setup with a parabolic lens and a pressure cell in a cryogenic environment using Monte Carlo simulations.

1. Introduction

The use of supermirror (SM) technology for neutron guides and beam focusing has ensured an increasing performance of neutron instruments (see for example [1], [2] and [3]). In particular the ability to produce supermirrors with large m-values on curved surfaces provide huge potential for improved instrument performance and new instrument concepts [4], [5].

Since this technology relies on the total reflexion of neutrons at a surface it is crucial to extend the neutron lens as close as possible to the sample to obtain maximum intensity gain. In many situations this conflicts with the requirements on the sample environment such as the need of low or high temperatures, high pressures or magnetic fields by utilising cryostats, furnaces, pressure cells or magnets. Moreover, the ever accelerating development of new materials and the growing need to study their properties requires the ability to measure even small quantities of these new materials with sample sizes below 1 mm^3.

A logical step to resolve this dilemma is to incorporate neutron lenses into the sample environment. In this paper we would like to explore the feasibility and the potential to use SM-lenses in a cryogenic environment.

2. Experiments

To check the feasibility of our idea we have conducted several cryogenic tests. The SM which were used for these tests were prepared at PSI. Float glass substrates with an area of 50x50 mm^2 were coated with Ni-Ti SM-layers ($m = 3.6$). In first tests, these samples were repeatedly thermally cycled between 300 K and 77 K. After visual inspection, we did not observe any degradation of the film itself nor did we see any indications for lift-off of the SM-layers from the substrate.

Encouraged by our first tests we went on to study the neutron reflectivity properties of our SM-film as a function of temperature. We performed θ-2θ scans on the Morpheus reflectometer at the SINQ (PSI) to measure the q dependence of the reflectivity at 5.012 Å. The sample was

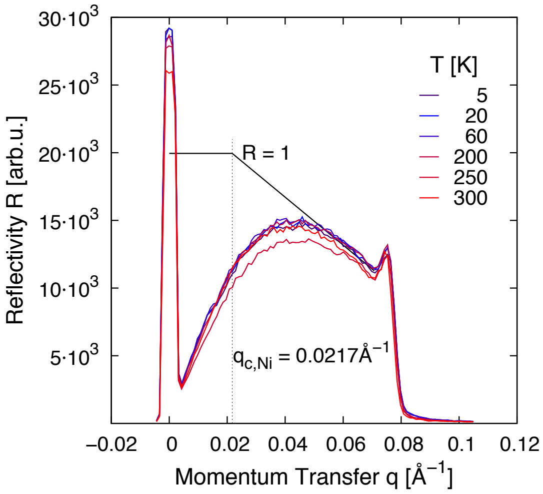

Figure 1. Temperature dependence of the reflectivity of a supermirror with $m = 3.6$. The wavelength for the experiment was chosen to be 5.012 Å. The deviation of the curve at 250 K is a result of the miss-alignment of the sample due to the thermal contraction of the sample stick. The peak at $q = 0$ is the observed direct beam. It was always measured to ensure that the geometrical configuration had not changed during the temperature scan.

installed in an Orange Cryostat, a cryostat with static exchange gas, to vary the temperature between 5 and 300 K and to ensure good thermalisation of the glass. The resulting data for a full temperature scan upon warming are shown in Fig. 1 omitting some intermediate temperature steps for clarity.

The measured reflectivity curves at low temperatures are unchanged as compared to the curve measured at room temperature. For the curve at 250 K small corrections to the sample alignment had to be made but the expected shape could not be fully recovered. However, the observed discrepancy is solely caused by a slight miss-alignment of the sample due to thermal contraction of the cryostat sample stick and not an effect of the SM. This can be concluded since we were able to almost recover the same shape and level of reflectivity by a realignment of the instrument.

3. Monte Carlo Simulations

To estimate the potential of a cryogenic lens we have run Monte Carlo simulations using McStas [7], [8]. As mentioned before, one promising application would be the combination of a neutron lens with a pressure cell where samples are generally small and surrounded by the pressure medium and the cell material. Previous work [6] reporting on the combination of a pressure cell and a neutron lens at ambient temperature achieved gain factors of 3 using a horizontal and vertical focussing unit. Concerning pressure cells available at SINQ, the largest potential for improvement is held by the Paris-Edinbugh pressure cell (PE-cell) in conjunction with its closed cycle refrigerator (CCR). Details about this device can be found in [9] and [10]. Figure 2 shows a sketch of the important components and dimensions.

Here, we considered a parabolic lens. The lens has a length of 75 mm which is limited by the diameter of the innermost radiation shield of the CCR. In this model we only consider vertical focusing. We set the focal length to 14 mm and the vertical height of the lens to 1.5 mm at the exit which results in a 5 mm opening at the beam entrance. The supermirrors were chosen to have $m = 7$ with a reflectivity of 64 %. That is the highest m-value which is currently available. We allowed for a 1 mm clearance between the lens and the anvil which would be largely occupied by the mirror substrate in a real setup.

The simulations were performed assuming a neutron source with predefined divergence. Figure 3 shows the dependence of the neutron intensity gain on the vertical beam divergence at the focal point with a chosen sample height of 1 mm. The intensity gain is defined as the count ratio at the sample position with and without lens. The wavelength of the beam was set

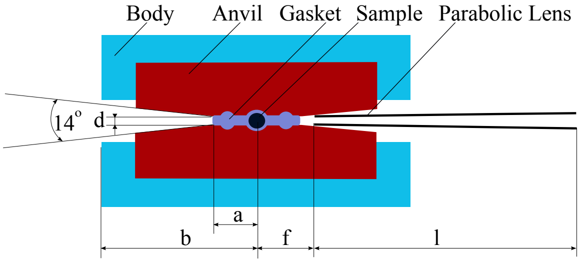

Figure 2. Schematics of the inner components of a PE pressure cell. The sample is enclosed in a pressure gasket together with the pressure medium. The gasket has a height (d) of 2 mm and a radius (a) of 10 mm. The anvils allow an opening angle of 14° with a total radius (b) for the anvil together with its holder of 37 mm. The focal length of the lens (f) was set to 14 mm and its length (l) of 75 mm is determined by the diameter of the inner radiation shield which has a diameter of 180 mm.

to 5.0(±0.2) Å. As one would expect the gain increases with decreasing divergence since a single sharp focal point can only be observed for a parallel incoming beam.

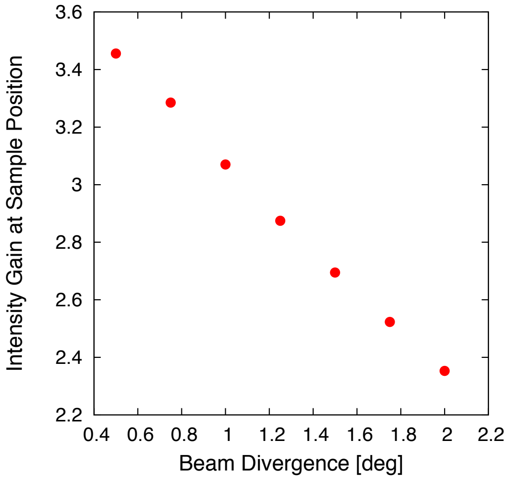

Figure 3. Intensity gain as a function of vertical beam divergence. The calculations were done for an assumed sample height of 1 mm and a neutron wavelength of 5 Å.

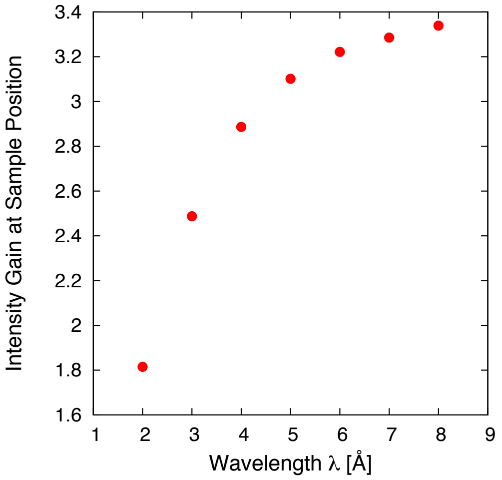

Figure 4. Intensity gain as a function of wave length. The vertical divergence of the beam was set to 1°. Samples height was 1 mm.

For a selected divergence of 1 % the wavelength dependence for the investigated setup is shown in Fig. 4. Depending on the incoming wavelength gain factors between 1.8 and 3.4 can be achieved.

In Fig. 5 we examine the influence of the SM-coating reflectivity on the intensity gain. The wavelength was set again to 5 Å and curves for maximum and minimum beam divergence were considered. For both cases we find a saturation of the gain for $m > 5$. We think this observation is a consequence of the geometrical constrains of the setup. The m-value is proportional to the critical angle of the total reflection. In the example considered, the beam divergence as well as the curvature of the lens are rather small and total reflexion is always fulfilled for $m > 5$. In case of the small divergence data set, this saturation starts a bit earlier than for the large divergence data set.

The effect of the sample size on the intensity gain is also very important. As one can clearly see in Fig. 6 small samples benefit most from this kind of intensity enhancement. This becomes clear if one recalls that the intensity gain is basically the ratio of the total beam to the direct

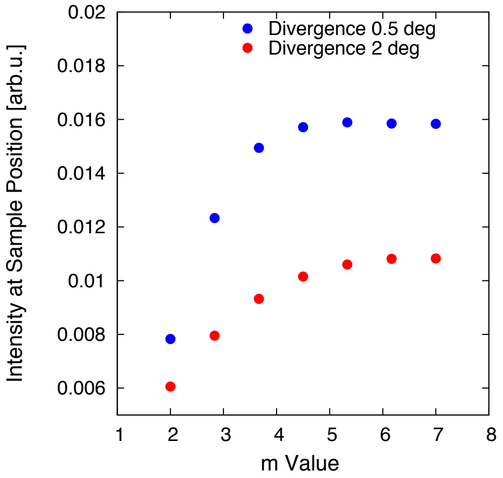

Figure 5. Intensity at the sample position as a function m-value. For smaller divergences the choice of m-value becomes less important.

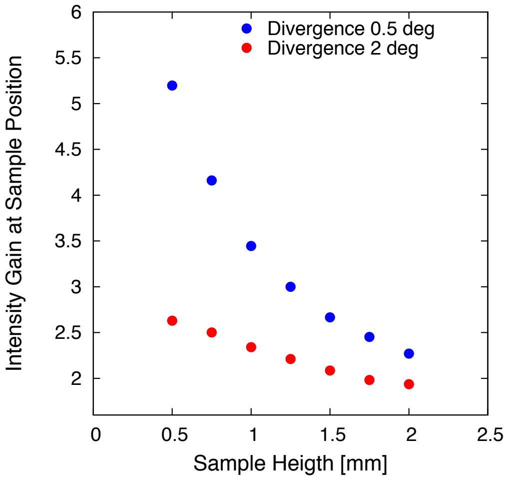

Figure 6. Intensity gain as a function of sample size at $\lambda = 5\,\text{Å}$ and $m = 7$.

beam at the sample . The intensity of the direct beam scales with the sample size (i.e. here, it scales with the height) while the reflected beam does not loose intensity assuming that the sample is perfectly in focus. This, however, is only true if the beam divergence is exactly zero. For finite divergences the reflected beam is also loosing intensity due to the blurring of the focal spot.

4. Conclusion

We have shown that it is technically feasible to envision neutron optics inside a cryogenic sample environment. Moreover, we have shown that such a lens would yield sizeable intensity gains for small samples. Furthermore, we have shown that the finite beam divergence has the largest influence on the performance of the lens. The gain could be further enhanced by increasing the length of the lens which in case of the PE-cell and its CCR would only require a new set of modified radiation shield to increase the length by a factor two. Ultimately, intensity gains of the order of 10 and higher could be achieved by combining a cryogenic and an external neutron lens.

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