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# 14.2
# The Neutron Silicon Lens : An update of the thermal neutron lens results

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**Abstract**
This paper introduces the concept of the Neutron Silicon Lens (NSL) and provides and update on the experimental results achieved to date. The NSL design is a cylindrical neutron lens based on the use of multiple neutron mirrors supported and separated by silicon wafers. Such lenses would have many applications in both the primary and scattered beams on neutron instruments, and would lead to immediate improvements where the sample to be illuminated is small, as in high pressure or engineering strain scanning instruments.

## 1. Introduction

Effective thermal neutron lenses offer considerable advantages in instrument design by adding to the techniques available to improve fluxes. This is particularly true for time of flight instrumentation - which up to now has not had a method, apart from neutron guides, of de-coupling the divergence of the neutron beam from its flight path. Such a de-coupling is extremely important for optimal instrument design, since both the divergence and flight path play a role in determining the intensity and resolution of the neutron scattering instrument, and maximising the performance often requires that they are adjusted separately.

The techniques available for neutron lens construction are Bragg diffraction [1,2], refraction [3], magnetic field gradients [4,5] or reflection [6-10]. The focusing effects of the first three of these techniques are wavelength dependent, and are hence generally unsuited to white-beam instrumentation. Such lenses would not therefore be generally useful at time-of-flight sources such as ISIS (Rutherford Appleton Laboratory, UK) or the third generation spallation sources, such as the SNS in the US or JSNS in Japan.

Reflection techniques, however, are well suited to time-of–flight instrumentation since the trajectories of neutrons at different energies through such lenses are, to first order, the same. An example is the Kumakhov lenses [6-9] which uses grazing incidence multiple reflection within capillaries to guide neutrons to a focal point. These polycapillary devices are well suited to white beam instrumentation since their focal length remains independent of the neutron wavelength, but have the disadvantage that their focal spot size is wavelength dependent.

More recently [10] it has been demonstrated that the 'lobster eye' lens used previously with X-rays [11,12] will produce a focussing effect with neutrons. However, although this device will focus in two planes simultaneously the 'lobster eye' lens uses hollow rectangular glass channels to achieve the effect. Since the glass surface has a very small critical angle for neutron reflection, such devices will be of limited applicability, since the beam divergence that they are able to accept is considerably smaller than the (relatively) wide divergence of neutron beams achievable with super-mirror coated neutron guides. Also, the 'lobster eye' lens is based on equally spaced channels which results in many neutrons either not being reflected, or multiply reflecting in the device. In either of these cases they then do not contribute to the focussed image.

## 2. The Silicon Lens Design

The NSL design proposed earlier [13] is also based on reflection, and is therefore able to be used in white beam, spallation neutron instrumentation. It is based on the same geometrical principle used in the 'lobster eye' micro-channel plate (MCP) devices [10-12] or grazing incidence X-ray lenses (as used, for example on the ROSAT satellite), but incorporates a number of significant changes.

By restricting the lens to be a cylindrical device (i.e. focussing in a single plane) it is able to fully exploit the use of supermirror optics [14-16] available for neutron reflection. Secondly, it is designed so that every neutron makes just one reflection in the lens, and all neutrons incident on the lens are reflected. Finally the design incorporates true focussing optics, as opposed to the plain mirror geometry available in MCPs. In addition their design uses single crystal silicon (a material highly transparent to neutrons) to support the mirror surfaces, rather than hollow channels.

It should be noted that while the NSL designs presented here are able to focus neutrons in a single plane, full 3-dimensional focusing may be achieved by using two NSL in series.

Fig 1 illustrates the basic idea of the design. The ideal NSL employs ellipsoidal surfaces to bring the neutrons to a true focus at position 'b'. The diagram has been simplified, showing only 3 ellipsoidal surfaces. By using a elliptical design for the mirror surfaces, it can be arranged that, with the use of variable wafer thicknesses, all neutrons will be scattered from a stack of silicon wafers of constant thickness.

A Monte Carlo simulation of the ellipsoidal design in Fig.1 has been made using the geometrical arrangement illustrated in Fig 2. In this simulation a 1mm(h) x 20mm(w) slit illuminates a NSL with a stack height of 20mm, and a silicon depth of 20mm. The NSL has a focal length of 500mm and is made up of 140 Si wafers ranging in thickness from around 400 to 25 microns. Because it is impractical to use the very thin wafers required in the centre of the lens this simulation included no mirrors at all across the central 1.2mm of the lens. The intensity calculated from this simulation at the 2.5mm high detector at the focal plane is shown in Fig.3. This illustrates the fact that the lens performs as expected with 75% of the original neutrons that leave the 1mm illuminating slit (within the critical angle of the supermirror) arriving within a central 1mm area of the focal plane. The fact that less than 100% of the illuminating neutrons reach the centre of the focal plane is due to the omission of reflecting planes from the central 1.2mm of the lens.

## 3. First Experimental results

In the first test of the design, a stack of 146 (m=2) supermirror coated Si wafers was designed to have a focal length of 500mm. The mirror surfaces in this case were plane, rather than elliptical. In this arrangement the thickness of the Si wafers varied form 30 micrometers to 400 micrometers. Fig. 4 shows the intensities achieved both with and without the lens present in an experimental arrangement that corresponded to Fig. 2. The neutrons incident on the slit in this test had a wavelength in the range 6-7Å.

This result has demonstrated that a focussing effect can be achieved, although it is also clear from the raw data that imperfect focussing has been achieved, since the width (FWHMH) of the image of the original 1mm slit is between 2 and 3mm wide.

A more complete analysis of the results will be presented elsewhere [17] together with suggestions for improving this current performance.

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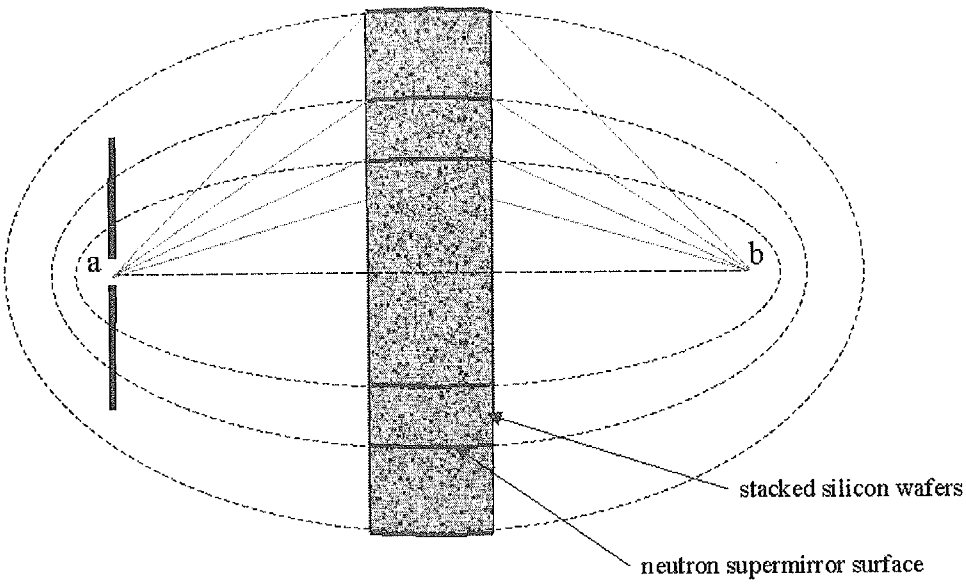


*Figure 1. A schematic diagram of the cross section of an elliptical design of NSL. In this design the supermirror surfaces are constrained to lie on the surfaces of ellipses with common foci at 'a' and 'b'.*

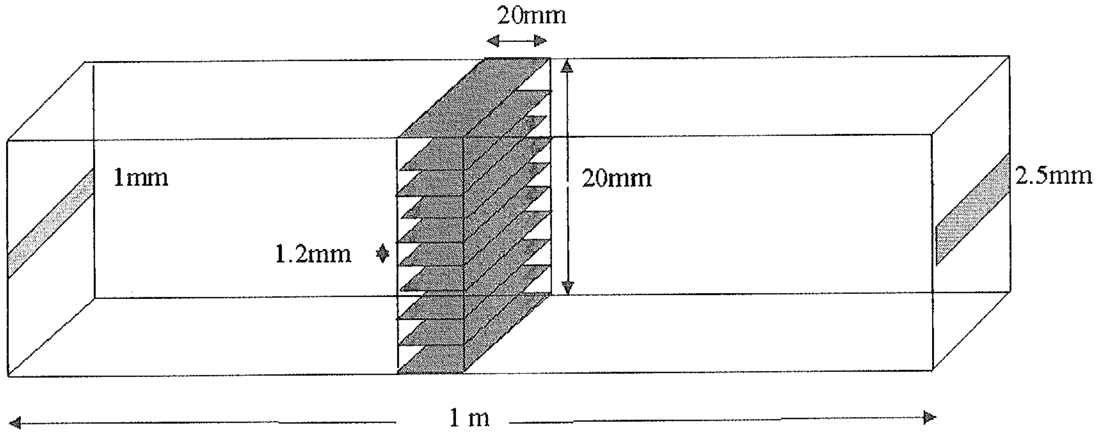


*Figure 2. The geometrical arrangement of the simulation of the elliptical lens designs. A 1mm slit at the left of the diagram acts as the source of neutrons, and this is imaged onto the 2.5mm detector shown at the right.*

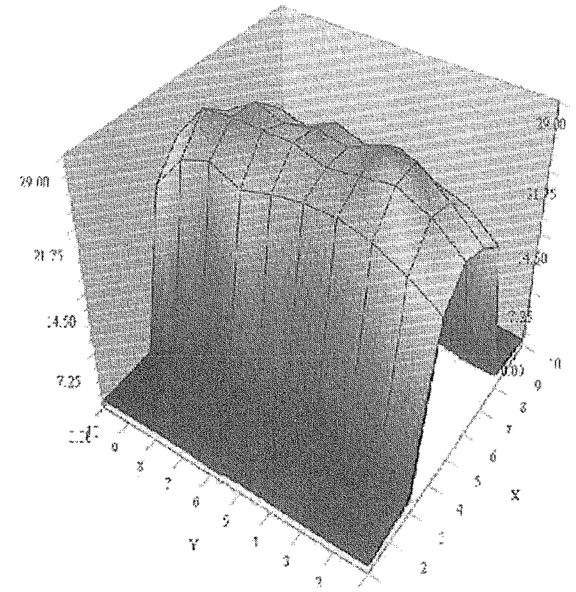

*Figure 3. The simulated intensity of 3Å neutrons reaching the 2.5x20mm detector in Fig.2*

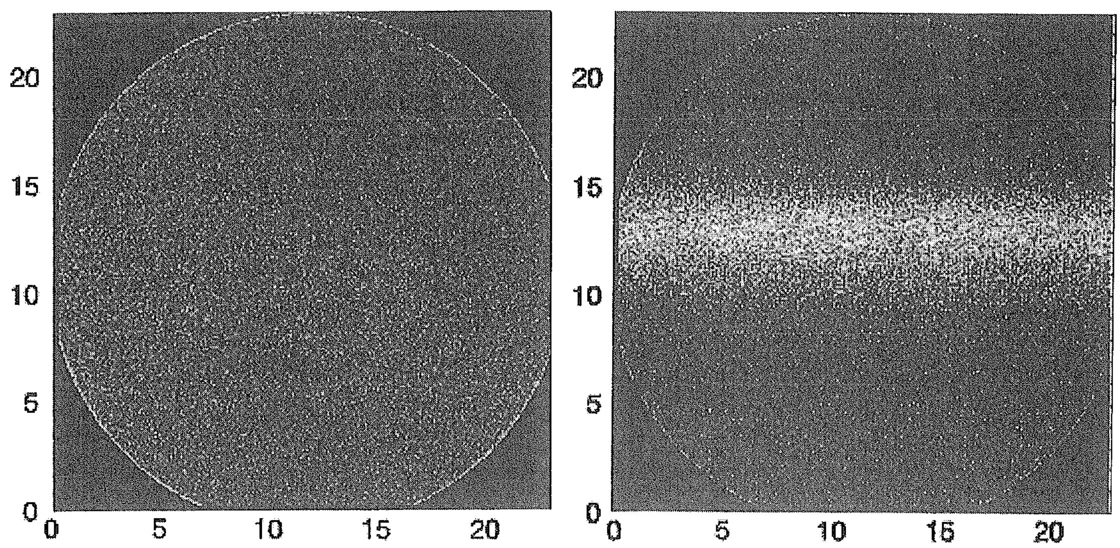


*Figure 4. The intensities recorded in an imaging camera (diameter of 25mm) both with and without the lens present in an experimental arrangement that corresponded to Fig. 2.*