VBPR – Variable Beam Profile Reflectometer

VBPR is a horizontal geometry neutron reflectometer capable of delivering a variable beam profile onto a sample surface as small as 1 mm^2 without the use of apertures in the immediate sample position. The instrument will take advantage of the pulse characteristics and brightness of STS combined with advanced focusing optics to deliver a broad wavelength band at high fluence. This permits the acquisition of an extended Q-range from a small sample area using a single instrument setting, enabling the study of small samples or small areas of a larger sample.

Science Drivers

Interest in surface and interfacial phenomena continues to increase across diverse scientific areas ranging from biology to geoscience. When coupled with isotopic substitution or complicated sample environments, neutron reflectometry (NR) remains a method of choice in the study of interfaces. However, current interest is shifting to samples that do not meet the traditional neutron reflectivity sample criteria of a large, homogeneous surface area. Examples include patterned or graded surfaces used to understand layer conformation and its effect on surface properties, solid-state diffusion over short length scales, hybrid (organic/inorganic) materials of technological interest with limited lateral dimension or heterogeneous surface structure, or materials in extreme environments and include topics such as:

- Nanopatterned surfaces formed by e-beam lithography have been proposed as platforms to investigate structure such as the conformation of suspended soft-surface coatings or protein conformation at the surface of a suspended lipid bilayer.[1] The ability to probe such systems on a millimeter length scale will eliminate the need to produce large patterned surfaces and open new areas of research.
- Formation of the solid-electrolyte interphase (SEI) is critical to the performance and safety of energy storage materials. It can be difficult to obtain a uniform electric field over large surface area electrodes, leading to lateral inhomogeneity in layer formation. The ability to define a small beam profile on the sample makes it possible to select specific areas or eliminate the need for large-area electrochemical cells altogether.
- The study of diffusion processes over short length scales (~ nm) is a developing area of research in energy storage, nanostructured, and semiconductor materials. In situ NR can play a major role in the study of such systems by using stable isotope substitution (e.g., $^6Li/^7Li$ in energy storage materials) and multilayered film configurations. VBPR will enable the use of much smaller samples eliminating concern over use of costly isotopes and more significantly, improve time resolution by improving the response time of heating and cooling samples.
- In general, large beam profiles average over the entire surface of the sample, losing information regarding lateral inhomogeneity. The ability to focus the beam to as small as 1 mm^2 will allow the user to "raster" a sample, effectively measuring variations in the scattering length density profile as a function of lateral position on the sample. This could allow NR measurements of nontraditional materials such as naturally occurring minerals or samples deposited onto irregular surfaces.

Science Requirements

The key requirement is for a reflectometer with an optics system designed to deliver a small, variable beam footprint) onto a horizontal sample without need for beam defining apertures very close to the sample for samples as small as 1mm x 1mm. Gains in beam intensity over an unfocused case should be ~30x to permit the measurement of reflectivity curves with $R<10^{-6}$ in fractions of an hour(see reference 2). In order to capture the reflectivity with a minimal number of measurements for ease in data analysis, the instrument must sample a broad wavelength band to maximize the measured Q-range ($\Delta\lambda>12$Å). The sample area must accept standard sample environments and provide for translation in the plane of the sample in order to raster the finely focused beam for areal studies and provide precise alignment for small area samples.

[1] G. Smith, et al., *Nano Research* **6**, 784 (2013).

Technical Description

Optimized for small beam footprints, VBPR will view the3 x 3 cm^2 highest brightness coupled moderator at STS. Like the kinetics reflectometer, it is desirable to place the sample position as close to the moderator as possible to maximize the Q-range sampled at a single instrument setting. However, the elliptical guide design that provides precise control over the beam profile may dictate placing the sample somewhat further from the moderator reducing the Q-range. For example, the elliptical focusing system proposed for the ESS Estia[2] is approximately 30 m long with the detector an additional 6 m from the sample. At this distance, a 13 Å bandwidth is available at the 10 Hz operating frequency of STS. Slow, kinetic studies will require twice this wavelength band and the chopper system must be designed to allow 5 Hz operation by eliminating intervening pulses. The instrument will require at least one (or more likely two) bandwidth choppers to define the wavelength band.

Key parameters of VBPR

Parameter	Description
Moderator	High-peak brightness coupled moderator (3x3 cm^2 face)
Beam Size	variable to provide a footprint on sample from ~ 1 mm^2 to several hundred square millimeters
Moderator–sample distance	30 m
Sample–detector distance	2 - 6 m (final distance is TBD)
Wavelength range	2.5 Å ≤ λ ≤ 25 Å (5 Hz) 2.5 Å ≤ λ ≤ 12.5Å (10 Hz)
Resolution	$\Delta\lambda/\lambda$ <0.05
Detector	^{3}He 2-dimensional position-sensitive detector (1 mm resolution)

[2] https://europeanspallationsource.se/estia-truly-focusing-reflectometer