Experimental report

25/01/2024

Proposal: 1-20-75 **Council:** 4/2023

Title: Resonant-enhancement signal and absorb-suppress noise for quantum-well resonator thin films

Research area: Physics

This proposal is a new proposal

Main proposer: Peng PAN

Experimental team: VASSILIOS KAPAKLIS
Peng PAN
Maximilian WOLFF
Adrien PERRICHON

Local contacts: Alexei VOROBIEV

Samples: F/V superlattice grown on MgO and LiF

Instrument	Requested days	Allocated days	From	To
SUPERADAM	4	3	03/11/2023	06/11/2023

Abstract:

The measurement of hydrogen dynamics in thin films by neutron scattering is a significant technical challenge due to the drastically reduced sample volume. Neutron wavefield enhancement in a quantum-well resonator has recently developed a possible solution to this issue. To further validate the method and reduce the background scattering, we propose using triple resonators and high absorption substrate LiF, Fe/V superlattice grown on LiF and MgO. We will compare the results from PSD (neutron reflectivity) and incoherent scattering detectors, to check if the signal is higher enough for the dynamics experiment. If successful, we will, in a subsequent experiment, measure the inelastic/quasielastic scattering from such a resonator.

Report on experiment 1-20-75(Proposal #88893 and #89758)

"Resonant-enhancement signal and absorb-suppress noise for quantum-well resonator thin films"

P. Pan, M. Wolff, M. Karlsson

Super Adam, PNR, 02–08 Nov. 2023

Introduction and state of science

The recent advancements in surface science, particularly with the discovery of 2D materials, have elevated it as a vital interdisciplinary field linking physics, chemistry, biology, crystallography, and materials science. This surge in interest stems from the crucial role surfaces and interfaces play in technological innovations. A key challenge in this domain is deciphering the atomic-scale structure and dynamics of these surfaces and interfaces. Neutrons, with their unique properties such as spin and low energy, emerge as an indispensable tool in material research. While neutron spectroscopy and neutron reflectometry have been used to study hydrogen diffusion in bulk crystals, surface-sensitive neutron experiments face limitations due to the brilliance of current neutron sources. Overcoming this limitation, using quantum resonators in samples has shown promise [1,2], especially in the study of metal hydrides, offering new avenues to explore structure and dynamics in thin-film systems.

We wanted to investigate the H dynamics in Fe/V multilayer thin film grown on MgO and LiF substrates. To achieve this goal, we designed triple resonator via resonant-enhance signal and absorb-suppress noise (LiF). The choice of LiF is due to its high neutron absorption. The measurements built on a previous experiment at the Super Adam of the ILL. The experiments aimed at improving the signal-to-noise ratio and looking for possible dynamic signals from H/D loading.

Experiment:

1. **Objective:**
   The primary aim of the experiment was to investigate resonant-enhancement signals and noise suppression techniques in quantum-well resonator thin films. (compare results from MgO and LiF substrates)
2. **Sample Preparation:**
   The vanadium hydride thin films (triple resonator, 30 nm, 35 nm, and 40 nm thick of V deposited on LiF and MgO substrates separately) prepared at Uppsala University, by established magnetron sputtering techniques.
3. **Instrument Configuration:**
   Super Adam instrument was configured for the experiment, including wavelength 5.21 Å, resolution (d_lambda/lambda) 0.004, and sample to detector distance 250 cm.

The measurements were mainly measured at two sample growths on LiF (sample 20231005-LiF) and MgO (sample 20231005-MgO) substrates, which were grown simultaneously. The experiment temperature was set on 473 K, on LiF substrate sample loaded with D2 at different pressures (200 mbar, 10.5mbar, 7.5 mbar, 5.1 mbar, 2.2 mbar, 0.1 mbar). And on MgO substrate sample loaded with H2 at different pressures (200 mbar, 50 mbar, 20 mbar, 10 mbar, 7 mbar, 4 mbar, 1 mbar, 10-6 mbar). A test sample 20230508-MgO was only measured as-prepared condition. The preliminary results from those three samples are shown below.

Preliminary results and analysis:

Fig. 1 shows the NR profiles (++) of the triple resonator thin film on sample 20231005-MgO and 20231005-LiF. The film on MgO shows more oscillation,

1. **PNR Data:**

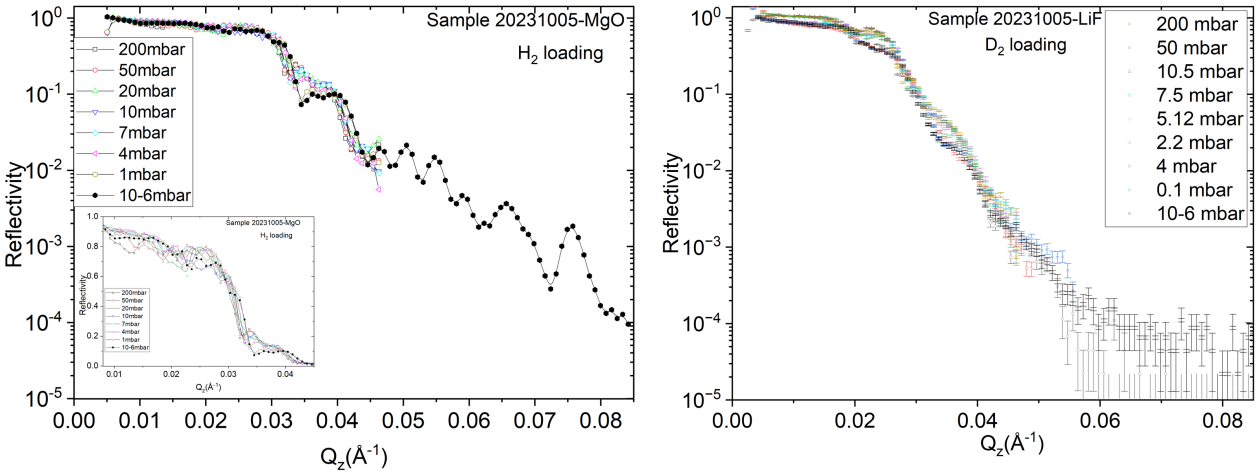

Figure 1. The measured NR profiles (++) of the triple resonator thin film on samples 20231005-MgO (left panel) and 20231005-LiF (right panels) under different pressure.

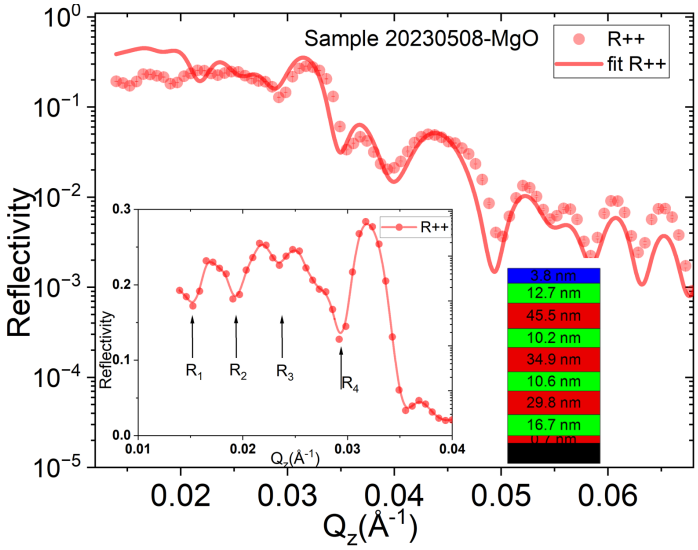

Figure 2. The measured polarized neutron reflectivity profiles of the triple resonator thin film in the as-prepared state at on a log scale. The inset is the low-Qz portion of data plot on linear scale.

Figure 2 shows 4 resonance states on sample 20230508-MgO at low-Qz. The 20231005-MgO observes only one. A more detailed data analysis is in progress. From the data analysis, the sample 20230508-MgO shows better data quality and might be worth a follow-up measurement with loading H_2/D_2 at Super Adam.

Reference

[1] M. Wolff, et al. , Nuclear Spin Incoherent Neutron Scattering from Quantum Well Resonators. Phys. Rev. Lett. 123, 016101 (2019).

[2] Perrichon A, et al. Resonant enhancement of grazing incidence neutron scattering for the characterization of thin films[J]. Phys. Rev. B, 103(23), (2021).