Aging memory and glassiness of a driven vortex system

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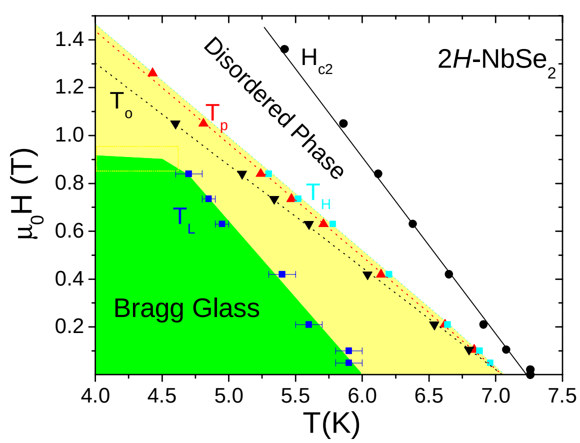
Supplementary Information

A. Sample details

Samples used in the measurements were cleaved from a undoped single crystal of 2H-$NbSe_2$ and then into rectangular bars with dimensions 4.4 mm × 0.8 mm × 6 μm. The transition temperature and transition width of the samples are Tc = 7.2 K and ΔTc = 130 mK, respectively. The magnetic field was applied along the c-axis, and the transport current was applied in the a-b plane.



Supplementary Figure 1: Phase diagram of the 2*H*-$NbSe_2$ sample (Fig.4 in PRL96, 017009 (2006)).

Figure 1 shows the phase diagram obtained from the samples used in the glassy dynamics study. In this letter, we focus on the Bragg glass region (green area).

B. Measurement Setup

The measurement setup was adapted to the signal level and rise time. For low saturation voltages (<5μV), where the voltage response can normally be measured with ~100ms time resolution, we used a Keithley 2400 source-meter to apply current and a Keithley 2182 nanovoltmeter to measure voltage. The time resolution of the low-level measurement system was set to ~ 45 ms.

For higher saturation voltages (>10μV) where the response time is shorter (<10ms), the current pulses were generated by a BNC 625A arbitrary function generator. To measure the voltage response, we combined a low noise voltage amplifier (gain=1000, input noise: $4nV/Hz^{1/2}$) with a Tektronix 2232 oscilloscope. Each set of the measurements were typically taken 16~64 times and the data were averaged for better signal to noise ratio.

C. Preparation of vortex states

In the FC procedure the sample was first warmed to 10 K (above Tc) in a fixed magnetic field generated by a superconducting magnet working in persistent mode, and then quenched to the measurement temperature T. The duration of a typical FC cycle was ~ 5 minutes. The pulse measurement was carried out about 60s after the measurement temperature was reached.

D. Effect of sample quality

Sample quality (purity, crystal quality, etc.) profoundly affects the glassy behavior. Thus far aging was only observed in samples of intermediate purity as characterized by the transition temperature and width (T_c= 7.2 K and ΔT_c =130 mK) and by the remanent resistance ratio RRR=R(300K)/R(8K)~14.

In the "dirty" limit we studied Fe doped samples, where $T_c < 6.2$ K and RRR ~ 9, (reference 17). In this case we observed no evidence of relaxation when the external force was removed. In the very clean limit we studied undoped samples with T_c= 7.1 K, ΔT_c =50 mK and RRR ~40. Here again aging was not observed, and the voltage response in the 2nd pulse appears to be instantaneous as long as the 1st pulse is applied sufficiently long so that voltage reaches the saturation value.

In contrast, for all the samples studied, the results of the "step-pulse" measurements were independent of sample quality indicating that the evolution of the system during the first pulse depends only on the pulse amplitude and not on the energy landscape.

E. Effect of quench times

We carried out a limited study of the second pulse response as a function of the quench time of the FC state from 10K to the target temperature. Quench times were varied from several minutes to 8 hours. No measurable quench time dependence of the aging parameters was found.