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## Dissertation outline

When a small AC shear force is applied to many-particle systems with random distributions, particles gradually self-organize to avoid future collisions and transform into an organized configuration, which is called a dynamic ordering. By contrast, when the particles with organized configurations are driven by a small DC drive, they are gradually pinned by random pinning centers and transform into a disordered configuration, which is called a dynamic disordering. Associated with these phenomena, novel nonequilibrium transitions, such as a reversible-irreversible flow transition, and new phenomena, such as a transient memory effect, have been reported in different physical systems. However, the nature of the dynamic ordering and disordering remains still unclear, which belongs to the fundamental and general problem in physics. In this thesis, we perform a systematic study on the dynamic ordering and disordering, focusing on the change in the particle configuration. We use a vortex system of amorphous $Mo_xGe_{1-x}$ films with weak random pinning, which provides an ideal platform for these investigations. This is because individual vortices are regarded as perfectly uniform particles due to quantization, their motion can be well controlled by applied currents $I$, and the mean velocity can be detected precisely from the voltage $V$.

To obtain the information about the vortex configuration associated with the dynamic ordering by AC drive, we start with developing two-step measurements of the transient voltage $V(t)$ in response to the AC currents. We found, unexpectedly, that the vortex configuration during the AC dynamic ordering is not microscopically homogeneous but consists of organized region (OR) and disordered region (DR). With increasing the number of AC shear cycles, the ratio of OR to the total sample area increases monotonically from zero to 1 at the steady state. We have also found a memory effect in the irreversible phase: namely, the information of the input shear amplitude is memorized in the final as well as transient vortex configuration, and it is readable by subsequent readout measurements.

We also study using the two-step measurements of $V(t)$ how the vortex configuration evolves associated with the dynamic disordering by DC drive. In contrast to the results of the dynamic ordering by the AC drive, the vortex configuration during the DC dynamic disordering is always homogeneous. To explore the origin for the coexistence regions observed in the dynamic ordering by AC drive, we further examine the dynamic ordering by DC drive. The results show that the transient configuration is not homogeneous but separated into the two regions: the initially prepared highly DR and the finally reached moderately DR. We propose a model that as the dynamic ordering by the DC drive proceeds, the number and/or the size of flow channels grow, and finally the system reaches a uniform plastic-flow state. The present results indicate that AC drive is not indispensable for the formation of the coexistence regions.

Next, we study the interplay between the dynamic ordering and disordering when the AC and DC drives coexist. The results show that random organization caused by the AC drive is suppressed with increasing the superimposed DC drive, and finally vanishes as the DC voltage $V_{dc}$ is equal to the amplitude of the AC voltage $|V^{\infty}|$, where the vortices move in the forward direction only. Thus, it is concluded that for random organization to occur by AC drive, return motion with respect to the random pinning centers is indispensable. It is also found that even in the steady state, the vortex configuration created with the superimposed DC and AC drives is not microscopically homogenous but consists of DR and OR. This is in contrast to the case of AC or DC drive only, where the coexistence regions appear only in the transient state. With increasing $V_{dc}$, the area ratio of OR decreases monotonically from 1 to zero at $V_{dc}=|V^{\infty}|$, where random organization in the input experiment disappears. The present result also implies that OR emerges dynamically in disordered DC plastic flow when the AC drive is superimposed with the DC drive. Physics of plastic flow has been studied extensively more than two decades to understand, e.g., the plasticity and friction of solids. This work is probably the first to uncover the partial ordering of plastic flow by superimposed AC drive.

Finally, we study a general, long-standing problem how elastic objects escape from an underlying pinning potential and exhibit dynamical flow states with an increase in DC drive. For this purpose, we examine a change in the vortex configuration in the steady state as a function of DC *I*, using the two-step measurements of $V(t)$. It is found that in the intermediate *I* regime between plastic flow and flux flow at large *I*, the vortex configuration is not homogeneous but separated into two regions: highly DR characterized by plastic flow at small *I* and OR characterized by the moving lattice at large *I*. With increasing *I*, the area ratio of OR increases monotonically from 0 to 1. Such behaviors have not been predicted theoretically or experimentally.

The results presented in this thesis, including the experiment, analysis, and interpretation, are very simple and clear, though non-trivial. The two-step measurements developed in this work are the first to be used in the superconductivity research and useful to study the dynamic vortex configuration. While the origin of the coexistence regions in the vortex configuration has not been fully clarified, our results suggest that the disordered initial configuration and/or the dynamic-ordering process may play a key role in the emergence of the coexistence states. We believe that the findings presented in this thesis and the experimental method developed here are of interest to broad researchers and stimulate further research in various areas.