Application of time-domain interferometry to study dynamics of lipid membranes

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Lipid molecules are basic building block of cell membranes, which are thought of two-dimensional fluid and are dynamic platform of various biological functions. The time scale of the dynamics spans from atomic and molecular motions in ps scales up to fusion of cell membranes in second scales or longer. We have used neutron spin echo spectroscopy, one of quasi-elastic neutron scattering techniques that covers ps to 100 ns scales, in order to study lipid membrane dynamics, and we describe thermal fluctuations of membranes are dictated by the membrane's elastic and viscous properties. Membrane viscosity is a fundamental property that controls the molecular transport and structural rearrangement in lipid membranes. Given the importance of cell membranes to a variety of biological functions, various techniques have developed to determine the values, while the observed values differ from one method to another and vary by many orders of magnitude. In order to understand the nature of the membrane viscosity, we have used time-domain interferometry as well as neutron spin echo spectroscopy to access nanoscale dynamics of lipid alkyl chains. Lipid alkyl chain correlation peak appears around 1.5 $Å^{-1}$ (or the correlation length of approximately 4.5 Å), and the temperature dependence of the relaxation time of the structural correlation was measured in different phases. Above the lipid melting temperature, where the lipid membranes are in fluid phase, the relaxation time is of the order of 1 ns, and the estimated membrane viscosity is ~10^{-9} Pa s m, which is in the middle of the variety of membrane viscosities measured by various techniques. The time-domain interferometry technique is suited to measure relaxation dynamics in the gel phase (at lower temperatures), where the relaxation time of the alkyl tail correlations is estimated on the order of 10 ns and the membrane viscosity is calculated on the order of 10^{-8} Pa s m, which is about an order of magnitude larger than those in the fluid phase. These results are consistent to a general understanding in the difference in the time scale of the dynamics between the fluid and gel phases. The present experiment is the first of this kind, and the results suggest that the structural relaxation of lipid alkyl chains characterize the membrane viscosity.