Non-linear Rheology of Lyotropic Lamellar Phases

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スメクティック液晶やリオトロピック系のラメラ相のような一次元周期構造を有する系のレオロジーを議論する。我々は転位ループの運動が散逸に寄与すると仮定し、そのダイナミクスを考察することにより、ずり速度と応力の関係を与えるスケーリング則を導いた。さらに非イオン界面活性剤 ($C_{12}E_5$) 水溶液におけるラメラ相のレオロジー測定を行い、理論的な予測の検証を行った。その結果、予測に近いスケーリング則を確認するとともに、ずり速度の揺らぎが平均のずり速度に比例するという興味深い現象を発見した。

The rheology of smectic liquid crystals or lyotropic lamellar phases is a long standing problem (1). Although several aspects may affect their rheological properties, various experiments suggest that defects such as dislocations or disclinations play an important role. Here we present a theoretical and experimental study on the nonlinear rheology of a lyotropic lamellar phase under weak shear. Our interest is to find out the physical mechanism which underlies the universal rheological behavior of 1D layered structures.

We first suggest that under an applied shear, the layers tilt due to the motion of dislocations caused by the Peach–Koehler force. Subsequent tilt and dilation leads to an undulation instability of the layers, which results in the creation of dislocation loops. Next we estimate the averaged density and size of dislocation loops as a function of the applied shear rate. For this purpose, we assume that the dislocation loops cause energy dissipation from the viscous force acting on edges. We predict a scaling relation between the shear rate $\dot{\gamma}$ and the stress σ such that

$$\dot{\gamma} \sim \frac{\mu_{\rm e}}{B^{1/2}}\sigma^m \qquad m = 3/2$$

where $\mu_{\rm e}$ is the edge climb mobility and B is the layer compression modulus. Hence the rheology response is a shear thinning behavior. Notice that this scaling differers from that by Meyer *et al.* (2).

The above prediction has been checked with the use of a binary system consisting of nonionic surfactant ($C_{12}E_5$) and water. We performed a shear stress controlled measurement of the

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lamellar phase with different composition and temperature. For example, when $\phi = 35$ wt% and $T = 339$ K, the exponent was found to be $m = 1.44 \pm 0.08$ as shown in Fig.1. This is in good agreement with our theory. The effects of changing the composition and temperature will be discussed. Interestingly, we also found that the measured shear rate oscillates as a function of time. We show that its characteristic frequency is proportional to the averaged shear rate. This result may reflect our picture that the production rate of the dislocation loops increases linearly with the shear rate. Our findings will be compared with other experimental results as well as existing theories.

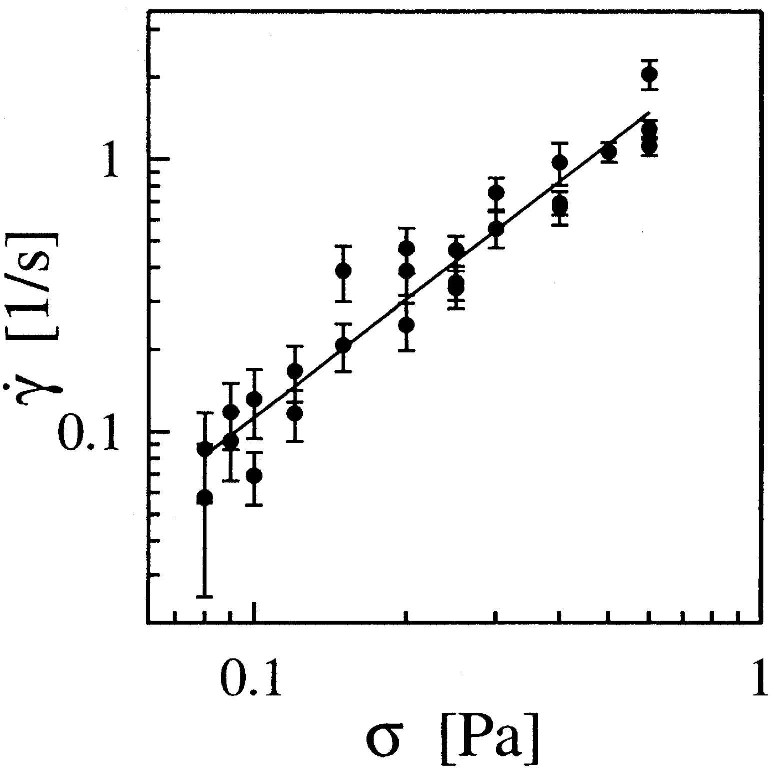

Figure 1: Measured shear rate as a function of applied stress in the lamellar phase of $C_{12}E_5$/water binary system. The composition and the temperature are $\phi = 35$ wt% and $T = 339$ K, respectively. The solid line has a slope 1.44 ± 0.08.

References

(1) R. H. Colby, C. K. Ober, J. R. Gillmor, R. W. Connelly, T. Duong, G. Galli, and M. Laus, Rheol. Acta **36** (1997), 498.

(2) C. Meyer, S. Asnacious, and M. Kléman, Eur. Phys. J. E **6** (2001), 245.