Upper critical field of layered organic superconductor, (TMTSF)$_2$ClO$_4$

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One of the Bechgaard salts, (TMTSF)$_2$ClO$_4$ exhibits superconducting transition at about 1.4 K. When the magnetic field is applied parallel to the conducting ab plane, it is reported that the upper critical field ($H_{C2}$) amounts to about 5 T at low temperatures, which is much higher than Pauli limit field ($H_{Pauli} \approx 2.6$ T) [1-3]. So far, $T_C$ and $H_{C2}$ have been mainly determined by resistance measurements. In low dimensional systems, it is well-known that resistance decrease due to large superconducting fluctuations might cause over-estimation of $T_C$ and $H_{C2}$. Therefore, thermodynamic measurements are required to determine the superconducting phase diagram unambiguously.

To re-examine $H_{C2}$ of (TMTSF)$_2$ClO$_4$, we have performed systematic measurements of the field-angle-dependence of magnetic torque and interlayer resistance ($R_{ZZ}$) for a same single crystal. The magnetic torque curves (Fig. 1) show characteristic angular dependence at field angles close to 90 degrees ($H$//plane). Distinct steep linear slope at 90 degrees is caused by Meissner or pinning effect of vortices along the perpendicular to the superconducting ab plane. The sudden changes to the background are interpreted as lock-in transitions of the vortices.

These behaviors are suppressed as the field increases, and is not appreciable above $H_{Pauli}$. The resistance $R_{ZZ}$ is zero within the experimental error below $H_{Pauli}$ but shows finite values above $H_{Pauli}$. These results clearly show that $H_{C2}$ does not exceed $H_{Pauli}$. We will show the phase diagram determined from these measurements and discuss the superconducting fluctuation effect on these quantities.

Fig. 1: Angular dependence of magnetic torque at about 0.2 K