

# Non-linear conduction in the charge-disproportionated phase of $\text{La}_{1/3}\text{Sr}_{2/3}\text{FeO}_3$

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## Abstract

We measured the resistivity under pulsed high electric field up to 4000V/cm in  $\text{La}_{1/3}\text{Sr}_{2/3}\text{FeO}_3$  thin film which exhibits charge disproportionation (CD) at 185K. To eliminate the self-heating effect we adopted thin films (rather than bulk samples) and micro-fabrication with the focused ion beam technique. Current-voltage characteristics showed non-linear behavior above 1000V/cm at 170K; this behavior appears only in CD phase. The threshold field  $E_{th}$  increases as temperature is decreased. Negative differential resistivity and delay in pulse wave form which are characteristic for de-pinned charge-density-wave were also observed. These suggest an occurrence of collective motion of carriers under CD phase.

*Key words:* charge disproportionation ; pulsed high electric field ; non-linear conduction

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## 1. Introduction

In the perovskite  $\text{La}_{1/3}\text{Sr}_{2/3}\text{FeO}_3$  (LSFO) charge disproportionation (CD) occurs at 200K. This transition is described as :  $3\text{Fe}^{\frac{4+}{3}} \rightarrow 2\text{Fe}^{3+} + \text{Fe}^{5+}$ . Various studies indicate that in the CD phase there exists layered spin and charge order stacking along  $[111]_{\text{cubic}}$  direction, which can be regarded as a coupled spin density wave (SDW) and charge density wave (CDW). It is of importance to investigate the similarities and differences of the nature of the CDW in comparison with well-known CDW systems. In such systems resistivity measurement under pulsed electric field revealed that there exists non-Ohmic conduction due to the collective sliding motion of CDW at above certain threshold electric field typically of the order of 10mV/cm.

In the neighborhood of  $T_{CD}$ , the LSFO system has relatively as low resistivity as about 10mΩcm. It is difficult to apply high electric field to the low resistance samples, because of the self-heating by the Joule effect. For constant voltage measurement the generated heat

$Q$  caused by the applied voltage  $V$  is given by  $Q = V^2 t / R$ , where  $R$  and  $t$  are the resistance of the sample and time duration, respectively. There are two ways to suppress  $Q$ : (i) use of pulsed voltage to minimize  $t$ , (ii) making large the sample resistance  $R$  by controlling the sample's shape. In the present work we used both ways, and the method (ii) was realized by utilizing the thin films and micro-fabrication with Focused Ion Beam (FIB) into a shape with narrow width. This enabled us to apply up to 4000V/cm of electric field on LSFO sample with negligible self-heating effect or sample degradation.

## 2. Experimental

Thin film sample was made by pulsed laser deposition (for details see [1]).  $(\text{LaAlO}_3)_{0.3}(\text{SrAl}_{0.5}\text{Ta}_{0.5}\text{O}_3)_{0.7}$  (LSAT) (100) was chosen as a substrate. The lattice constant of LSAT ( $a=3.868\text{\AA}$ ) is close to that of LSFO (in cubic notation  $a=3.867\text{\AA}$ ). The film thickness was 500Å. From the x-ray scattering profile the in-plane lattice constant of the film is slightly smaller than that

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of the bulk sample because of the epitaxial strain from the substrate.

After the deposition of the LSFO film the gold electrodes were vacuum-deposited. This is then micro-fabricated by the FIB technique. The typical sizes of the sample thus obtained were  $60\mu\text{m}$  in width and  $20\mu\text{m}$  in distance between the electrodes. The electrical contact between the electrodes and gold wires ( $50\mu\text{m}$  in diameter) was obtained by silver paste.

### 3. Result and Discussion

Figure. 1 shows the temperature dependence of resistivity in LSFO film before the micro-fabrication with FIB technique. The CD transition observed in thin films occurs at about 190K which is about 10K below the bulk value, probably due to the epitaxial strain.

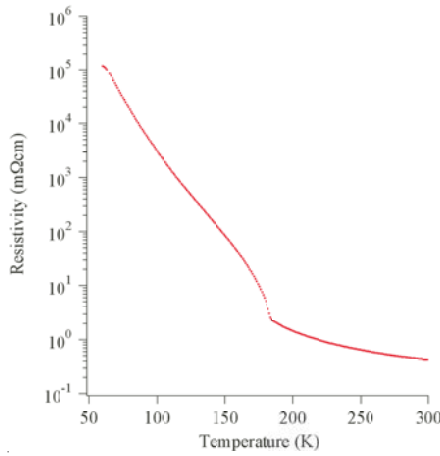


Fig. 1. Temperature dependence of resistivity in micro-fabricated LSFO thin film. Steep increase of resistivity at around 190K corresponds to CD transition.

Current density  $J$  vs electric field  $E$  relation is displayed in Fig. 2. Typical pulse time width is 1ms. For temperatures larger than  $T_{CD}$  ( $=185\text{K}$ ) the relation stays linear. Upon cooling below  $T_{CD}$  the threshold field  $E_{th}$  appears, above which the relation starts to deviate from the Ohm's law significantly. In the present study the direction of the applied voltage is along  $[100]_{\text{cubic}}$ . It is shown by the neutron diffraction that in the CD phase the ordered oxygen holes are stacked with its normal vector in  $[111]_{\text{cubic}}$  direction[2]. Therefore the applied voltage and ordered hole sheets form  $45^\circ$  to each other.

Pulse waveform observation by an oscilloscope revealed that there is a delay between the instant of field application and the instant of increase in current density. During the delay time the resistivity stays at the value for the low applied field. LSFO's delay time is at

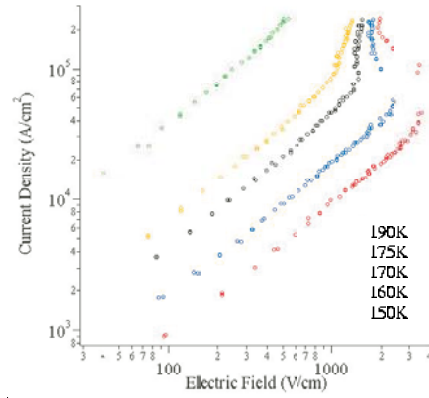


Fig. 2.  $J$ - $E$  characteristics.

least about 100 times longer than that of well-known CDW material  $\text{K}_{0.3}\text{MoO}_3$ . A gross estimate shows that the delay time approximately depends exponentially on the applied electric field. Violation of Ohm's law, delay in pulse response and its exponential dependence on electric field are the characteristic phenomena for the sliding of collective body constituted by the condensation of a number of carriers in CDW state.

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