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Proposal of controlled NOT gate using FQHE system and observation of large life time of laser triggered conductance change in LaSrCuO film with localization

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Abstract

According to a theoretical proposal denoting large decoherence time in fractional quantum Hall effect (FQHE) system, we studied the CO_2 laser irradiation effect on the $La_{1.95}Sr_{0.05}CuO_{4-\delta}$ film, whose electronic behavior is supposed to be described by FQHE caused by the unique zero-point oscillation of Cu electron. The irradiation induced conductivity change at room temperature shows the switching of hysteretic behavior triggered by the laser light. The effect remains after the irradiation for several days. The long life time can be explained by the large decoherence time of FQHE system, which is necessary for the feasibility of quantum computing. © 2002 Elsevier Science B.V. All rights reserved.

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Keywords: LaSrCuO film; IR laser response; Conduction hysteresis; Decoherence time

1. Introduction

Recently quantum computing is attracting wide attention [1]. It was shown that any quantum computer can be composed based on the "controlled NOT gate" [2,3], where the wave function is processed by control bit and target bit. The practical feasibility of the gate requires its decoherence time $\tau_D = 1/\gamma$ to be long enough for quantum-computing operations. Zurek [4] showed that at high temperature region $\gamma \sim k_B T g^2/h^4 c_s^3$, where g is the coupling constant between phonon and quantum system and c_s is the sound velocity. As the examples of the estimation of quantum-computing operation, the "resolution of the number N into factors" is known to take, even in an ideally conceived system, large numbers of processes in the order of $\sim\exp[\gamma(\log N^2)]$ [5], or to take substantial computation time as long as ~40 min for 2048 bits of N [6]. The estimation reveals that quantum computing is feasible either at (i) effectively zero temperature in hitherto-proposed system or in the new system with extremely small g. Two of the authors (M.S. and S.K.) proposed [7] that we can make a controlled NOT gate with very

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long τ_D by the use of the pseudo-spin state of fractional quantum Hall effect (FQHE) system, where the single particle wave function determining the pseudo-spin state has the effective size comparable to the 2D conduction-surface dimension. The large wave function size in comparison with the typical phonon wavelength suppresses g in vanishing level.

On the other hand, our group has been studying the macroscopic quantum behavior of perovskite thin film crystal effective even up to room temperature, which is based on the FQHE model caused by the unique zero-point oscillation of each Cu electron [8–12]. In this report is given the observation of the long life time of the quantum state change induced by the IR laser irradiation in $La_{2-x}Sr_xCuO_{4-\delta}$ film which may be related to the large τ_D in the FQHE system.

2. Effect of IR laser irradiation in small current conductivity

The $\|c$ conductance change of c-oriented $La_{1.95}Sr_{0.05}CuO_{4-\delta}$ film is measured in small current level at room temperature in the irradiation by IR lasers: CO_2 laser (wavelength $\lambda = 10.6$ μm, power $p_L = 10$ mW) or He–Ne laser ($\lambda = 3.4$ μm, $p_L = 10$ mW) [12]. The sample has multi-layer structure of Pd (5 nm)/(0 0 1)LaSrCuO (t_{LSCO} nm)/(1 0 0)$SrTi_{0.99}Nb_{0.01}O_3$ (1 mm)/Pd of area 5×5 mm^2. LaSrCuO film is made by PLD. ~30% of CO_2 laser power is found to penetrate the upper Pd electrode. The thickness t_{LSCO} of the measured samples ranges over 20–200 nm. ~90% of them show almost no or weak response, and ~10% show clear state change triggered by CO_2 laser irradiation. Since the substrate is conductive, we can study $\|c$ conductance of LaSrCuO film, where the voltage across the two Pd electrodes is measured by two terminal method.

Fig. 1 shows the clear state changes observed in the low level current (I)–voltage (V) relationship in a sample of $t_{LSCO} = 106$ nm with resistance $R = 33$ Ω. For clarity, the voltage difference $\Delta V = V$-*regression line* is studied. The same regression line is used for the data in one series of measurement. The hysteretic $\Delta V(I)$ is found before irradiation in

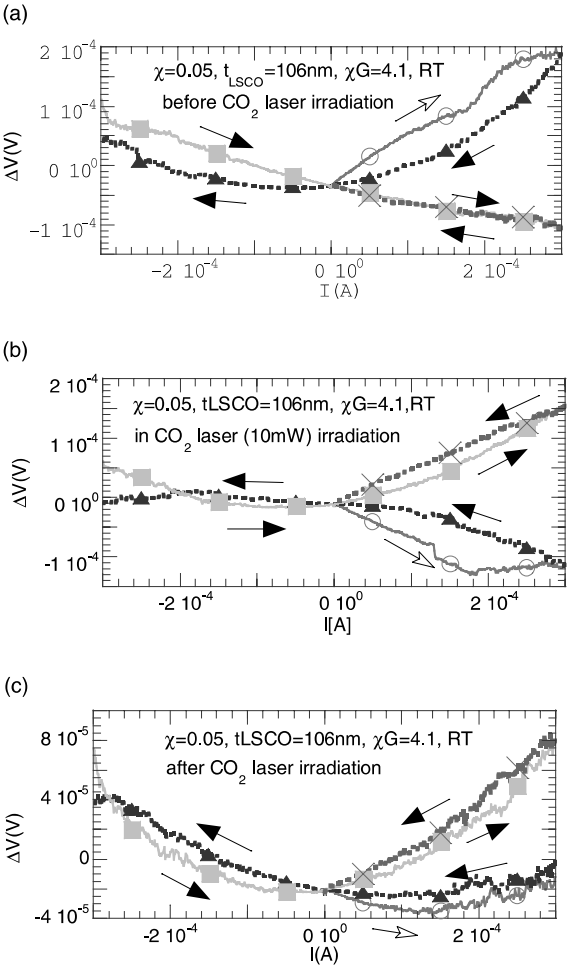

Fig. 1. Effect of 10 mW CO_2 laser irradiation on the hysteresis of low level I–V characteristics of c-oriented $La_{1.95}Sr_{0.05}CuO_{4-\delta}$ film.

I (mA) sweeping $0 \to 0.3 \to -0.3 \to 0.3 \to 0$ (see Fig. 1(a)). The curves of going and returning paths are continuous at the turning points when $I > 0$, but some discontinuity occurs when $I < 0$. After that sample is irradiated by CO_2 laser for 3 h to establish stationary state. Then keeping the irradiation, the I–V measurement is made (see Fig. 1(b)). In the region $I > 0$, the path array order in the voltage value is inverted in comparison with the pre-irradiation result. The inversion extends further to $I < 0$ region for small current strength, but the initial order recovers with the increase of the strength of negative current. It must be noted

that the inversion state is maintained after the irradiation for several days (see Fig. 1(c)). In the measurement made 2 weeks after, the state of I–V hysteresis almost recovers the initial state in the pre-irradiation measurement. The subsequent CO_2 laser irradiation represents the inversion effect. It is interesting that the He–Ne laser irradiation made after CO_2 laser irradiation accelerates the recovery to the initial state.

3. Conclusion

In order to study the theoretically prediction that the decoherence time is quite large in FQHE system, we investigate the CO_2 laser irradiation effect on the c-oriented $La_{1.95}Sr_{0.05}CuO_{4-\delta}$ film, where is shown that the behavior of electron system is supposed to be described by FQHE caused by the unique zero-point oscillation of Cu electron.

The effect of the laser irradiation on the small current conduction property at room temperature appears as the form change of the low current conductance hysteresis. The effect remains after the irradiation for several days. The observed long life time is interesting in connection with the theoretically predicted large decoherence time of the FQHE system.

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