Online: 1347-4073 / Print: 0031-9015

News and Comments

on " Resonant Photovoltaic Effect in Surface State Electrons on Liquid Helium "
J. Phys. Soc. Jpn. 81 (2012) 093601

The Enigma of Zero Resistance

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Published September 14, 2012

Vanishing electrical resistance is the most dramatic phenomenon in condensed matter. Superconductivity and the quantum Hall effect are the best-known examples of zero-resistance states (ZRSs). In the 21st century, the existence of new ZRSs were discovered in quite different situations. In two-dimensional electron systems (2DESs) exposed to microwave radiation in a small perpendicular field, the longitudinal resistivity ρ_{xx} vanishes when the microwave frequency matches an integer multiple of the cyclotron frequency of electrons. This zero-resistance phenomenon was first observed in high-mobility 2DESs formed in semiconductor heterostructures [1-3]. Although a number of studies have investigated ZRSs, the mechanism leading to the ZRS remains unclear [3].

Recently, Konstantinov and Kono discovered similar microwave-induced ZRSs in 2DESs formed on the free surface of liquid helium (^{3}He) [4]. A 2DES on liquid helium is significantly unique: it is not Fermi-degenerate, and it exhibits record high electron mobility owing to the absence of impurities on the free surface of helium [5]. A 2DES on helium is characterized by surface-state subbands with an intersubband energy on the order of 100 GHz (~10 K). Konstantinov and Kono found that the longitudinal conductivity σ_{xx} reaches zero when the microwave frequency matches both the intersubband transition frequency and an integer multiple of the cyclotron frequency of the electrons. In the 2DES in a magnetic field, the zero longitudinal conductivity means vanishing ρ_{xx}. Their discovery shows that the microwave-induced zero-resistance phenomena are a universal property of 2DESs.

In a more recent study, Konstantinov *et al*. examined the transient response and spatial electron distribution of a circular 2DES upon its irradiation with microwaves [6]. Surprisingly, under irradiation, the electrons accumulated at the center of the sample (Figs. 1 and 2). Konstantinov *et al*. confirmed that the electron accumulation occurred when the 2DES was in the ZRS. The nonequilibrium electron distribution produced an extremely large electrostatic potential energy approaching 1 eV (~10^4 K) per electron, which is considerably larger than any other relevant energy scales of 2DESs.

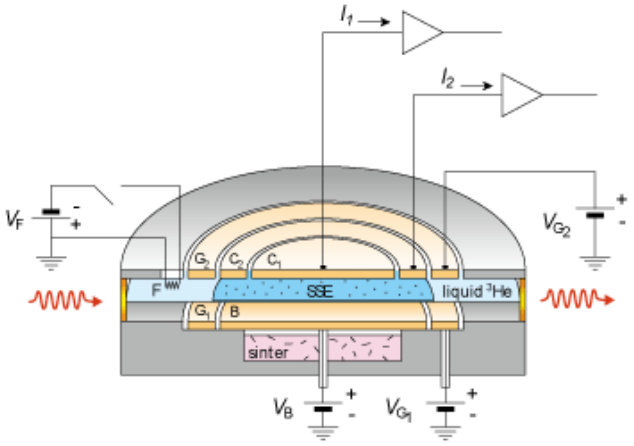

Fig. 1: Schematic diagram of the experimental setup. The 2DES is denoted as SSE (Surface State Electrons). [Figure is taken from Fig. 1 of ref. 6]

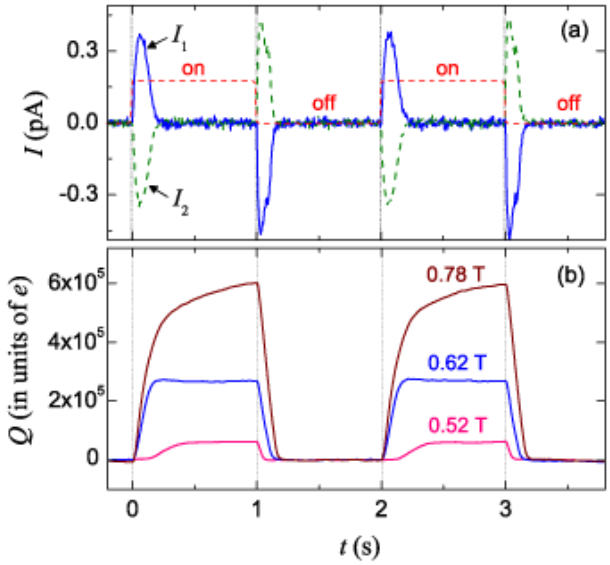

Fig. 2: (a) Transient signals of photocurrents I_1 (solid line, blue) and I_2 (dashed line, green) induced in the inner and outer electrodes, respectively, by the flow of the surface charge at temperature T = 0.2 K and magnetic field B = 0.62 T. The short dashed line (red) is a square waveform, which switches the microwave source ON (or OFF) at high (or low) signal levels. (b) Cumulative charge Q obtained by integrating the current I_1 at three values of B corresponding to the ω/ω_c = 4 (0.78 T), 5 (0.62 T), and 6 (0.52 T) conductance minima, where ω_c is the cyclotron frequency of electrons and ω is the microwave frequency. [Figure is taken from Fig. 2 of ref. 6]

This nonequilibrium charge accumulation is a novel *photovoltaic* effect. The microwave photons produce a DC electric field inside a 2DES even if there is no application of bias voltage from the electrodes. This photovoltaic behavior is likely related to the ZRS, which is possibly caused by the microwave-induced occupation of high Landau levels belonging to the second subband.

The photovoltaic effect identified by Konstantinov *et al.* suggests a solution to the problem of zero resistance in 2DESs. As compared to semiconductor heterostructures, a 2DES on liquid helium has the advantages of simplicity and an impurity-free nature. It is hoped that the mystery of zero resistance will be solved in near future.

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Note

The above article should be referred as "K. Shirahama: JPSJ Online—News and Comments [September 14, 2012]" when citing.

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