News and Comments

on "Resonant Photovoltaic Effect in Surface State Electrons on Liquid Helium"

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 $\rho_{xx}$ 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 $\sigma_{xx}$ 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 $\rho_{xx}$. 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.
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.
References

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

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