（様式４）

二国間交流事業 共同研究報告書

平成　23　年　3　月　31 日

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１．事　業　名　相手国（相手国（　ロシア　）との共同研究　対応機関（　RFBR　）

研 究 課 題 名：超伝導、電磁気、及び力学的ナノシステムにおける巨視的量子トンネル現象
（Macroscopic quantum tunneling in superconducting, electromagnetic, and mechanical nanosystems）

1.　全 採 用 期 間

平成　21　年　4　月　1　日 ～ 平成　23　年　3　月　31　日 （　2　年　0　ヶ月）

2.　研究経費総額

（1）本事業により交付された研究経費総額　5,000　千円

初年度経費　2,500　千円、　２年度経費　2,500　千円、　３年度経費　0　千円

（2）本事業による経費以外の国内研究経費総額　0　千円

5．研究組織

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6．研究概要（研究の目的・内容・成果等の概要を簡潔に記載してください。）

Abstract of research:

We proposed how to make a new quantum ratchet, applying an inhomogeneous critical current density current to a long Josephson junction. The ratchet-effect we proposed is based on the squeezing of the Josephson vortex due to either temperature fluctuations or quantum tunneling. A DC voltage arises in the system because the probability of the fluxon getting squeezed in one direction is higher than in the opposite direction. We showed that the DC voltage can change its sign at a temperature close to the crossover temperature between the classical and quantum regimes of the vortex squeezing.

We also performed an analysis of the experimental data on macroscopic quantum tunneling in a long Josephson junction made from $La_{2-x}Sr_xCuO_4$. Our theory agreed with the experimental data and provided insight into its physical origins.

The effect of dissipation on macroscopic quantum tunneling was also studied. The tunneling probability for the phases of superconducting electrons was calculated in single Josephson junctions as well as stacks of junctions. The dissipation was in a transverse component of the junction conductivity.

We prepared and published a very systematic, detailed, and complete review on the problem of Josephson plasma waves in layered high-T_c superconductors (including its generation, propagation, and quantum tunneling of Josephson vortices).

In agreement with our collaborators in Russia, we also performed additional investigations, extending our initial proposals.

We considered the following interesting idea: could layered superconductors behave as metamaterials? This could be potentially important, because metamaterials are very hard to make. We predicted and explained in detail why the existing high-T_c superconductors, as well as artificial superconducting heterostructures, could not be readily used as practical metamaterials.

We also studied the propagation of electromagnetic waves through a layered high-Tc superconductor. In a certain frequency domain, it is possible to distinguish two objects placed closer than a wavelength. However, this is only possible in a limited frequency range. We also predicted a new branch of the Josephson plasma surface waves in layered high-Tc superconductors. A main peculiarity of these waves is that they propagate in the frequency range of the bulk plasma waves.

We also completed several studies on graphene. A 2D Ising model with competing interactions of nearest and diagonal neighbors was solved by the methods of transfer-matrix and numerical Monte-Carlo simulations. For a hexagonal lattice, such an approach was demonstrated to be applicable for the study of defects in graphene. Moreover, we also studied electron states in a triangular quantum dot in graphene. Furthermore, the electronic structure of several graphene mesoscopic systems was studied. For instance, we showed that graphene nanoribbons are unstable to a spontaneous nucleation of the gap. One of the mechanisms of such an effect can be the deformation of chemical bonds. We completed and published a systematic and detailed review on the physical properties of mesoscopic graphene systems. It will likely become a very visible review in this growing hot field of research.