The developmrent of spintronic device research and thermoelectric effect in single-molecule magnet nano-junction

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Abstract

Very recently, with the develop of molecular magnetic materials, the single magnetic-molecular (SMM) has been demonstrated as a appropriate candidate to the basic components of the molecule-based spintronic devices . Unlike other nano-particles, the SMM are molecules with a relatively large net spin momnt and a significant uniaxial magnetic anisotropy . Below the block temperature,these molecules are trapped in one of the two metastable spin states . This bistability makes SMMs to be a suitable base for memory cells of future information storage and processing technology . So far, electronic tunneling spectra through the SMM have been experimentally demonstrated, and the spin dependent electronic transport properties through the SMM have also been extensively investigated, including magnetic signatures of the SMM in nonequilibrium condition, Kondo effect, the magnetization reversion, Berry phase and so on. In this program,we research the inelastic spin transport process between ltnerant electron and SMM's magnetic core.We put forward a series of new molecular spintronic device function as spin filter spin injector or molecule's spin signal controller. This research theme alsocan afford us more physics pictures about spin-polarized tunneling process in SMM's device. Such studies are valuable towards the development of nanoscale molecular spintronic devices based on electronic properties of the particip ating molecules.

Keywords

Spintronic; single-molecule magnet and thermoelectric effect.

1. Introduction

As we all know, the search for high-efficiency thermoelectric conversion technology and its thermoelectric devices are the goals that people have been pursuing and one of the most important challenges in the development of modern science and technology. Material science often uses a dimensionless merit to evaluate the ability of a material to convert thermal energy into electrical energy or vice versa. However, with the development of micromachining technology, the preparation technology of nanostructures is becoming more and more mature. Recent studies on thermoelectric effects in low-dimensional nanostructures have attracted great interest from physicists.： The reason is that the bulk material is usually limited by the Wiedemann-Fanz (WF) principle, and the quality factor is generally less than 1, which greatly limits the efficiency of thermoelectric conversion and its application. However, in low-dimensional nanostructures, theoretical and experimental work has confirmed that the Coulomb blockade effect will break the WF principle, leading to large quality factors. Taking quantum dot materials as an example, some work shows that the quality factor can exceed 2.5, so quantum dots have become a new darling of thermoelectric materials and thermoelectric devices. For industrial applications, if the quality factor of thermoelectric materials exceeds 3, there is a large-scale industrial production value, and it is expected to contribute to the research field of solving energy problems. Therefore, in the past ten years, based on various low-dimensional quantum confinement structures [1,2], such as quantum dots[3], quantum wires, single-layer graphite, single-molecule magnets, theories, experiments and technical applications of thermoelectric transport Aspects have received extensive attention, making thermoelectric transport research of mesoscopic quantum systems one of the most active frontier areas of condensed matter physics.

2. Single-molecule magnets (SMM)

2.1 The experimental work of single-molecule magnet devices

Unlike ordinary quantum dot materials, single-molecule magnets are a special type of zero-dimensional magnetic nanomaterial that can be magnetized by a magnetic field even with only a single molecule, retaining its magnetic properties after the magnetic field is removed, and The hysteresis loop appears in the curve of the magnetization with the external magnetic field. This particular intrinsic magnetic property is derived from the molecules themselves, rather than the long-range order and interactions that depend on the arrangement of molecules like traditional magnets. Since the first research team of Folk and Ralph in 2006 measured the tunneling current spectrum in single-molecule magnet devices, a large number of transport experiments based on this material were carried out, and nano-electronic devices with rich functions were developed，In 2010, the Zyazin team produced the first Fe4 single-molecule magnet three-terminal transistor.；In 2011, Rizzini and his team successfully fixed the TbPc2 single-molecule magnet on a ferromagnetic substrate. Then, the Wernsdorfer team combined a single-molecule magnet with a carbon nanotube to prepare a series of magnetic-molecule-coupled quantum dots, a composite nanodevice structure with magnetic molecules coupled to magnetic molecules, and successfully prepared a pair of TbPc2 molecules made by the spin valve; In 2013, Professor Wang Junzhong of Southwest University of China coupled Mn12 single-molecule magnets on Bi(111) substrates and observed the orbital energy level distribution of molecular magnets .

2.2 Theoretical study of single-molecule magnet devices

On the other hand, the experimental work of single-molecule magnet devices is also stimulating the theoretical study of electron transport in single-molecule magnet devices[4]. C.Timm proposed the Giant Spin (GS) model in 2006, and calculated the electron tunneling process in a single molecule under weak coupling. His theory well explained the negative differentials in the experiments of the Folk and Ralph groups. Conductance phenomenon and proposed a means to extend this phenomenon to high temperature regions. J. Barnes discussed the influence of spin polarized current transport on the molecular magnetic moment of monomolecular magnets. NRG technology was applied to study the transport properties of monomolecular magnet tunneling junction system and discussed the electron transport process of monomolecular magnets in kondo region. Professor Zeng Wei from the Institute of Solid State Physics of the Chinese Academy of Sciences used the first-principles principle to calculate the Spin Crossover effect in Fe2 single-molecule magnets and the electron transport of MnCu single-molecule magnets in gold electrodes. The electron polarization transport in the single molecular magnet under the bias voltage is further analyzed and the transport properties in the kondo region are further analyzed. Professor Yao Kailun from Huazhong University of Science and Technology used the first principle to simulate and calculate the magnetoresistance effect of single-molecule magnets. Professor Yu Jiuqing from Shanxi University studied the transport properties of single-molecule magnets such as Coulomb blockade effect and shot noise on the basis of C.Timm work. From these excellent research work at home and abroad, we can see that the single-molecule magnet device contains a wealth of novel and interesting physical phenomena, and the research of its electron transport problem will open up new research and development of information technology and molecular devices in the future. The road, experimental and theoretical research based on electron transport of single-molecule magnets will usher in a new upsurge.

3. Thermal spin effect in the nano molecule magnet device

Compared with electron transport research, thermoelectric transport in single-molecule magnets, especially spin-related thermoelectric effects, is still in its infancy and is a very new topic. Since 2008, Uchida et al. reported on the spin-beck effect of spin-detection in metal ferromagnets (spin Seebeck effect), This experimental approach to generating spin bias by thermal bias rather than voltage provides a new idea for the study of spin quantum devices. In 2009, Dubi and Di Ventra used the main equation to discuss the relationship between the spin-dependent quality factor and the charge quality factor n quantum dots with spin splitting Zeeman energy, and the pure self Eddy Current produced by thiermal gradients swirl. In 2010 and 2011, Professor Wang Ruiqiang of South China Normal University discussed the thermo-electric transport in single-molecule magnet systems, and calculated and analyzed that single-molecule magnet devices have good quality factors, suitable for high efficiency thermo-electric, thermal-spin-transformed devices, is a thermoelectric material with good theoretical expectations. These work show that the study of thermoelectric transport properties of single-molecule magnets can reveal rich physical connotations, and the research results provide theoretical support and ideas for the development and preparation of magnetic molecular thermoelectric devices.

Although the research on electron thermoelectric transport in single-molecule magnets has made preliminary progress, the control method of thermoelectric current of single-molecule magnet[5], the thermoelectric effect and the thermal spin effect in the device application of single-molecule magnets have yet to be further studied. Since the relaxation time of magnetic depolarization of single-molecule magnets is very long at low temperatures, the development of this material can be used as an effective way to break the traditional magnetic properties by size constraints in storage media, information processing, quantum computing, etc. The aspect has broad application prospects. Then, how to conveniently operate, rewrite and record the local magnetic number of the single-molecule magnet to complete the information storage process is also an important topic in the design of single-molecule magnet devices. Experimentally, with the polarization of the SP-STM technique, the spin state of a single magnetic atom can be electrically regulated by the spin transfer torque (STT) effect of the polarization current. Drawing on this idea, some theoretical work has attempted to control the large self of a single-molecule magnet by considering the exchange interaction between the spin-polarized flow and the molecular magnet, using the spin angular momentum transfer or the spin-biased electrode to control the general direction of rotation of a single-molecule magnet Then, a problem arises: Since the thermoelectric effect can generate thermal current and thermal spin current in a single-molecule magnet, does this imply that the temperature difference can be replaced by the voltage-driven and induced molecular magnetic moment? Experimentally, the phenomenon of using the thermal current generated by the thermal effect to control the magnetic properties of the material is called thermal spin transfer torque (TSTT). This effect studied in the molecular magnet system is seldom carried out. Since the parameters in the quantum dots of single-molecule magnets can be conveniently adjusted experimentally, the multi-body correlation effect and quantum interference phenomenon in single-molecule magnet quantum dots have important basic research significance, while utilizing thermally polarized electron transport. The magnetization state of the controlled single-molecule magnet has important application prospects for the development of new types of spin information storage devices.

4. Conclution

Based on the above discussion, based on the review of a large number of domestic and foreign literatures and the full analysis of the current status of single-molecule magnet research, combined with the thermoelectric transport problem in nanostructures, our research on the characteristics of magnetic single-molecule thermoelectric transport and its "Applications in the device" as our reporting topic. We believe that in the near future, the spin transport research in molecular magnets will become a powerful complement to the development of molecular spintronics, nanoelectron transport and semiconductor technology with its profound theoretical depth and wide application. The thermoelectric effect, the thermal spin torque transfer effect, the generation and application of thermal spin current, and the design and preparation of thermal spin devices in the electron spin transport process of single-molecule magnets will become spintronics research. important content. Therefore, the topics we applied for are based on these research contents. The research of this subject theoretically helps us to understand the thermoelectric conversion behavior in single-molecule magnet systems, reveal more and more new physics phenomenon , and at the same time, as an effective way to break through the traditional size constraints of traditional magnetic properties, single-molecule magnet molecules The study of magnetic thermal and electrical control methods will have great practical significance and research value for future ultra-high density molecular magnetic storage materials and high-performance spintronic devices.

Acknowledgements

This study is supported by Project of Philosophy and Social Science Research in Colleges and Universities in Jiangsu Province (2018SJA1456) and Special topic on Financial Development of Social Science Application Research Project in Jiangsu Province(18SCB-36).

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