3rd ICQMT 2025

3rd International Conference on Quantum Materials and Technologies

Emergence of Complexity from Individual Magnetic Atoms to Hybrid Magnet - Superconductor Quantum States

Distinguished Professor ROLAND WEISENDANGER

Roland Wiesendanger is professor of Experimental Physics at the University of Hamburg since 1993. His scientific interests include nanomagnetism and nanospintronics, unconventional superconductivity and topological physics. Since end of the eighties, he pioneered the technique of Spin-Polarized Scanning Tunneling Microscopy (SP-STM) which allowed the first real-space observation of magnetic structures at the atomic level, leading to numerous discoveries of novel types of magnetic states and phenomena in low-dimensional systems. Moreover, based on SP-STM studies of individual magnetic atoms and their distance-dependent interactions, all-spin atomic-scale devices could be demonstrated by combining single-atom manipulation techniques with spin-sensitive imaging at the atomic scale.

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Lecture Room: TBD

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Biography-continued

He has published 700 research articles, review papers and book chapters which have been cited more than 45.000 times. He is author of two textbooks and editor of nine books and eight conference proceedings. He has presented more than 600 invited talks at international conferences, universities, and research institutes. He is Doctor Honoris Causa of Poznan University of Technology and a member of numerous academies and scientific societies. He has received numerous prizes and awards, including three Advanced Grants of the European Research Council (ERC), the Julius Springer Prize for Applied Physics, the Heinrich Rohrer Grand Medal and Prize, the Philip Morris Research Prize, the Karl Heinz Beckurts Prize, the Max Auwärter Prize, and the Gaede Prize.

Abstract

The Spin-Polarized (SP-) STM technique [1], based on the detection of vacuum tunneling of spin-polarized electrons between a magnetic tip and sample [2], has allowed getting unprecedented insight into the static and dynamic properties of magnetic structures from the meso- and nano-scale down to the level of individual atoms [3] and molecules [4]. Atomic-resolution SP-STM studies have revealed fundamental magnetic properties of various material systems, including magnetic oxides [5], diluted magnetic semiconductors [6], as well as anti- [7,8] and ferromagnetic [9] metal films, where the magnetism is carried by either localized or itinerant electronic states. Temperature-dependent SP-STM studies have revealed the characteristics of magnetic phase transitions, while magnetic-field dependent SP-STM investigations led to the powerful technique of nano- and single-atom magnetometry [3,10]. By combining SP-STM with inelastic electron tunneling spectroscopy (IETS) [6], electrical pump-probe techniques [11] or time-resolved studies [12,13], the spin dynamics of individual adatoms or nanostructures could directly be revealed. Moreover, the combination of SP-STM with single-atom manipulation techniques [14] has allowed the investigation of tailored nanomagnets [15], built up atom-by-atom, as well as the fabrication of prototypes of all-spin atomic-scale logic devices [16]. In addition, the combined use of SP-STM and single atom manipulation has revealed the role of the spin degree of freedom in atomic-scale friction [17].

Besides fundamental studies at the level of individual atoms, SP-STM has proven to be an extremely powerful method for revealing complex non-collinear spin states in magnetic nanostructures, leading to the discoveries of chiral magnetic domain walls in magnetic nano-scale stripes [18,19], chiral spin spiral states in ultra-thin films [20,21] and atomic wires [22,23], and a novel class of interface-driven skyrmionic lattice states [24]. By combining the observation of such complex spin states with local manipulation based on spin-current injection from the magnetic SP-STM tip [12], the writing and deleting of individual skyrmions could be demonstrated [25], thereby paving the way towards novel concepts of information technology based on the use of topological rather than electrical charges [26].

STM-based single atom manipulation techniques were also used to fabricate well-defined defect-free 1D atomic chains as well as 2D arrays of magnetic adatoms on s-wave superconductor substrates with high spin-orbit coupling [27-35]. The spin structure of these low-dimensional adatom arrays have been characterized by SP-STM [1,30], while scanning tunneling spectroscopy measurements reveal the evolution of the spatially and energetically resolved local density of states as well as the emergence of zero-energy bound states at both chain ends above a critical chain length [27,33]. In order to confirm the interpretation of the zero-energy states as Majorana quasiparticles, we have used Bogoliubov quasiparticle interference (QPI) mapping of the 1D magnet-superconductor hybrid systems for directly probing the non-trivial band structure of the topological phases as well as the bulk-boundary correspondence [31]. Such experiments constitute the ultimate test and rigorous proof for the existence of topologically non-trivial Majorana states [35].

Besides reviewing these exciting developments, we will focus on very recent experiments which aim at combining the control of single magnetic atoms with the design of quantum states in artificially fabricated quantum corrals with proximity-induced superconductivity [36]. In particular, it will be demonstrated how non-local detection schemes of coherent Yu-Shiba-Rusinov quantum projections can be realized based on atom-by-atom constructed quantum boxes [37]

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