**B. Verkin Institute for Low Temperature**

**Physics and Engineering**

**National Academy of Science of Ukraine**

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**IV INTERNATIONAL WORKSHOP**

**ON POINT-CONTACT SPECTROSCOPY**

**WORKSHOP PROGRAM**

**March 25 - 28, 2024**

**Kharkiv, Ukraine**

**ORGANIZER**

**B.Verkin Institute for Low Temperature Physics and Engineering**

**of the National Academy of Sciences of Ukraine**

**Address: ILTPE, 47 Nauky Ave., Kharkiv 61103, UKRAINE**

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**ORGANIZING COMMITTEE**

**Prof. Naidyuk Yurii - Chairman**

**Dr. Kvitnitskaya Oksana**

**Dr. Terekhov Andrii**

**E-mail: naidyuk@ilt.kharkov.ua**

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**WORKSHOP PROGRAM**

**(Kyiv time, GMT+2**)

**March 25**

**9:45**

***Yurii Naidyuk***

OPENING & TO THE 50th ANNIVERSARY OF YANSON POINT-CONTACT SPECTROSCOPY

**10:30**

***Robert Shekhter***

MAGNETIZING A BCS SUPERCONDUCTOR BY POINT-CONTACT INJECTION OF SPIN-POLARIZED COOPER PAIRS

**11:15**

***Alexandre Zagoskin***

QUANTUM ANALOGUES OF DISSIPATIVE CIRCUIT ELEMENTS

**11:45**

***Jan van Ruitenbeek***

CHIRALITY INDUCED SPIN SELECTIVITY: AN OPEN PROBLEM IN SINGLE-MOLECULE JUNCTIONS

***b***0

***a***0

**2 nm**

***a***0

**Break 12:30 – 13:00**

**13:00**

***Hermann Suderow***

ATOMIC SIZE CONTACTS AND VISUALIZATION OF QUANTUM MATERIALS WITH VERY LOW TEMPERATURE SCANNING TUNNELING MICROSCOPY

**13:30**

***Gernot Goll***

A BRIEF HISTORY OF POINT-CONTACT SPECTROSCOPY IN KARLSRUHE

**14:00 – 14:30 *Reserved/Discussion***

**March 26**

**9:30**

***Jian Wang***

EMERGENT SUPERCONDUCTIVITY IN TOPOLOGICAL MATERIAL/METAL HETEROSTRUCTURES

**10:15**

*X.Y.Hou, M.D. Zhang, W.L.Zhu, X.M.Hu, Y.D. Gu, F.Zhang, G. F. Chen, N. Hao,* ***L. Shan,***

APPLICATION OF POINT-CONTACT SPECTROSCOPY IN THE STUDIES OF TOPOLO-GICAL SUPERCONDUCTIVITY AND VORTEX DYNAMICS

**10:45**

*Dongting Zhang, Lichang Yin, Chufan Chen, Xiaofeng Xu, Youguo Shi****, Xin Lu***

POINT-CONTACT SPECTROSCOPY STUDY ON SUPERCONDUCTORS UNDER

PRESSURE

**11:15**

*Bernat Olivera****, Carlos Untiedt***

KONDO SCREENING IN SINGLE ATOM CONTACTS OF TRANSITION AND RARE-EARTH MATERIALS

**11:45**

***D. Daghero,*** *E. Piatti, N.D. Zhigadlo, R.S. Gonnelli*

A MODEL FOR CRITICAL CURRENT EFFECTS IN POINT-CONTACT ANDREEV-REFLECTION SPECTROSCOPY

**12:15**

*D. Massarotti, H. G. Ahmad, R. Satariano, R. Ferraiuolo, P. Mastrovito, G. Serpico,*

*A. Levochkina, Z. Iqbal, G. Ausanio, M. Esposito, C. Granata, P. Lucignano, D. Montemurro,*

*L. Parlato, A. Vettoliere, A.F. Volkov, R. Fazio, G. P. Pepe &* ***F. Tafuri***

FERROMAGNETIC JOSEPHSON JUNCTIONS: PROPERTIES FOR POTENTAIL APPLICATIONS IN QUANTUM CIRCUITS

**12:45**

***M. Strohmeier****, F. S. Herbst, P. Haiber, D. Weber, E. Schee*r

CURRENT-INDUCED SWITCHING IN ATOMIC-SIZE CONTACTS

**13:15**

***Maxim Tsoi***

POINT CONTACTS IN SPINTRONICS

**13:45 – 14:15 *Reserved/Discussion***

**March 27**

**9:30**

*Takeshi Saito, Akira Sugimoto,* ***Toshikazu Ekino****, Alexander M. Gabovich*

OBSERVATION OF ZERO-BIAS CONDUCTANCE PEAK ABOVE *T*c AT FeSe1-*x*Tex BY BREAK JUNCTION TECHNIQUE

**10:00**

***A. Sugimoto,*** *K. Matsumoto, T. Saito, D. Yoshida, T. Ekino, M. Tanaka, A. M. Gabovich*

SCANNING TUNNELING SPECTROSCOPY AND BREAK JUNCTION SPECTROSCOPY OF THE 2D LAYERED NITRIDE CHLORIDE SUPERCONDUCTOR **-TiNCl AND THE RELATED MATERIALS

**10:30**

***G. Motoyama****, T. Mutou, M. Kuninaka, M. Adachi, A. Yamaguchi, A. Sumiyama*

PRESSURE DEPENDENCE OF THE BCS RERLATION ON TIN: IMPROVEMENT OF METHOD FOR POINT-CONTACT SPECTROSCOPY UNDER PRESSURE

**11:00**

***Masanobu Shiga,*** *Tatsuya Kawae*

ELECTRONIC DENSITY OF STATE IN HEAVY FERMION SYSTEMS STUDIED BY POINT-CONTACT SPECTROSCOPY

**11:30**

***G. Kamarchuk****, O. Pospelov, V. Vakula, E. Faulques*

QUANTUM POINT-CONTACT SENSORS

**12:15**

***Anatolie Sidorenko****, Vladimir Boian, Maria Lupu, Andrei Prepelitsa*

BASE ELEMENTS FOR SUPERCONDUCTING ARTIFICIAL NEURAL NETWORK

**12:45**

***R. S. Gonnelli,*** *E. Piatti, G. Prando, G. Gavello, C. Tresca, G. A. Ummarino, P. Carretta, G. Profeta, D. Daghero*

POINT-CONTACT ANDREEV-REFLECTION SPECTROSCOPY and MULTI-GAP SUPERCONDUCTIVITY in hydrogen-intercalated 1*T*-TiSe2

**13:15– 13:45 *Reserved/Discussion***

**March 28**

**9:30**

***V. N. Krivoruchko,*** *V. Yu. Tarenkov*

point-contact spectroscopy of collective excitations in multiband proximity-coupled spin singlet-triplet frequency even-odd superconducting condensates

**10:00**

***M. Belogolovskii****, E. Zhitlukhina M. Gregor, T. Plecenik*

SELF- ASSEMBLED NANOFILAMENT TECHNIQUE FOR POINT CONTACT SPECTROSCOPY OF SUPERCONDUCTORS

**10:30**

*D. L. Bashlakov,* ***O. E. Kvitnitskaya,*** *S. Aswartham, G. Shipunov, L. Harnagea, D. V. Efremov, B. Büchner, Yu. G. Naidyuk*

ELECTRON-PHONON INTERACTION, MAGNETIC PHASE TRANSITION, CHARGE DENSITY WAVES AND RESISTIVE SWITCHING IN VS2 AND VSe2 REVEALED BY YANSON POINT CONTACT SPECTROSCOPY

**11:00**

***G. Pristáš,*** *G. C. Gruber, Mat. Orendáč, J. Bačkai, J. Kačmarčík, F. Košuth, S. Gabáni,*

*P. Szabó, CH. Mitterer, K. Flachbart*

ENHANCEMENT OF CRITICAL TEMPERATURE IN SUPERCONDUCTING HIGH-ENTROPY ALLOY THIN FILMS THROUGH NITROGEN ADDITION

**11:30**

***D. Menesenko****, A. Shapovalov, A. Parra, A. Aliev, V. Tarenkov, I. Gavrysh,E. Zhitlukhina,*

*M. Belogolovskii*

NON-LOCAL AND POINT-CONTACT MEASUREMENTS OF TRANSPARENT SUPERCONDUCTOR FILMS

**12:00**

***M.V. Kosevich,*** *V.S. Shelkovsky*

IMPACT OF I. K. YANSON'S INVENTIONS ON ADVANCEMENT OF FIELD IONIZATION MASS SPECTROMETRY FOR MOLECULAR BIOPHYSICS PROBLEMS

**12:30 – 13:00 *Reserved/Discussion***

**March 29**

**Great & Holy Friday**

**ABSTRACTS**

*(chronological order)*

**EMERGENT SUPERCONDUCTIVITY IN TOPOLOGICAL MATERIAL/METAL HETEROSTRUCTURES**

**JIAN WANG**

*International Center for Quantum Materials, School of Physics, Peking University, Beijing 100871, China*

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Since the superconductivity was observed in the three-dimensional Dirac topological semimetal Cd3As2 single crystal using non-superconducting metallic tips in the point-contact experiment [1], there has been increasing interest in the field of condensed matter physics regarding the superconductivity that is induced via interface engineering in the heterostructure of a topological (semi)metal and a nonsuperconducting metal. Due to the topological non-trivial band structures of topological (semi)metals, the superconducting states emerging at their surfaces may inherit the topological non-trivial properties and become topological superconducting states [1]. In recent years, the kagome magnet has attracted extensive attention and the superconductivity in itinerant kagome lattice magnets may present a promising path toward topological superconductivity but is hard to realize. By depositing the metallic films or using point-contact spectroscopy, we successfully induce the novel superconductivity at the interface of kagome Chern magnet TbMn6Sn6 and metal heterostructures [2]. The anisotropy of the superconducting upper critical field suggests that the emergent superconductivity is quasi-two-dimensional. Remarkably, the interface superconductor couples to the magnetic order of the kagome metal and exhibits a hysteretic magnetoresistance in the superconducting states. Further taking into account the spin-orbit coupling, the observed interface superconductivity can be a surprising and more realistic realization of the p-wave topological superconductors theoretically proposed for two-dimensional semiconductors proximity-coupled to s-wave superconductors and insulating ferromagnets. Our findings of robust superconductivity in topological-Chern-magnet/metal heterostructures offer a new direction for investigating spin-triplet pairing and topological superconductivity.

[1] He Wang, Huichao Wang, Haiwen Liu, Hong Lu, Wuhao Yang, Shuang Jia, Xiong-Jun Liu, X. C. Xie, Jian Wei and Jian Wang. "Observation of superconductivity induced by a point contact on 3D Dirac semimetal Cd3As2 crystals" Nature Materials **15**, 38 (2016).

[2] He Wang, Yanzhao Liu, Ming Gong, Hua Jiang, Xiaoyue Gao, Wenlong Ma, Jiawei Luo, Haoran Ji, Jun Ge, Shuang Jia, Peng Gao, Ziqiang Wang, X. C. Xie and Jian Wang. "Emergent superconductivity in topological-kagome-magnet/metal heterostructures" Nature Communications **14**, 6998 (2023).

**ENHANCEMENT OF CRITICAL TEMPERATURE IN SUPERCONDUCTING HIGH-ENTROPY ALLOY THIN FILMS THROUGH NITROGEN ADDITION**

**G. PRISTÁŠ 1, G. C. GRUBER 2, MAT. ORENDÁČ 1, J. BAČKAI 1,3, J. KAČMARČÍK 1, F. KOŠUTH 1,4, S. GABÁNI 1, P. SZABÓ 1, Ch. MITTERER 2, K. FLACHBART 1**

*1 Institute of Experimental Physics, Slovak Academy of Sciences, Watsonova 47, 040 01 Košice, Slovakia*

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*Straße 18, 8700 Leoben, Austria*

*3 Faculty of Electrical Engineering and Informatics, Technical University, Letná 9, 042 00 Košice, Slovakia*

*4 Institute of Physics, Faculty of Science, P.J. Safarik University, Park Angelinum 9, 041 54 Košice, Slovakia*

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We have studied the influence of nitrogen incorporation on the superconducting transition temperature *Tc* of TiNbMoTaW high-entropy alloy (HEA) films deposited using high-power impulse magnetron sputtering. By measuring the temperature dependence of resistivity of (TiNbMoTaW)Nx nitrides, we observe a significant increase of *Tc*, from 0.62 K for x = 0 up to 5.02 K for x = 0.74. With a further increase of x, *Tc* is decreasing and reaches 1.08 K for x = 0.97. The eightfold *T*c enhancement seems to be associated with the incorporation of light N atoms into the face-centered cubic lattice and with the x-dependent enhancement of the electron-phonon interaction, which may related to the high configuration entropy in high entropy alloys. Measurements in the magnetic field show that the upper critical fields *Bc2* of (TiNbMoTaW)Nx with x > 0.15 provide *Bc2*/*Tc* > 2 T/K ratios, which are above the weak-coupling pair breaking limit. Additional heat capacity measurements show that the superconductivity in the ~1 μm thick films is bulk in nature. Moreover, using point-contact spectroscopy (PCS) we were able to determine superconducting energy gap 2Δ. Results of PCS show that the superconducting state in HEA nitrides is consistent with conventional weak-coupling phonon-mediated superconductivity. The proposed strategy of nitrogen incorporation into high entropy alloys may pave a pathway towards tailoring their superconducting properties, especially their *Tc*[1].

[1] G. Pristáš, G. C. Gruber, Mat. Orendáč, J. Bačkai, J. Kačmarčík, F. Košuth, S. Gabáni, P. Szabó, Ch. Mitterer, K. Flachbart, Acta Materialia **262**, 119428 (2024).

**MAGNETIZING A BCS SUPERCONDUCTOR BY POINT-CONTACT INJECTION OF SPIN-POLARIZED COOPER PAIRS**

**R. I. SHEKHTER**

*Department of Physics, University of Gothenburg, SE-412 96 Göteborg, Sweden*

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Properties of a point-contact weak link between two BCS superconducting leads, which has the form of a non-superconducting nanowire with a strong Rashba spin-orbit coupling are discussed. We show that such a weak link induces a spin-polarization of injected superconducting Cooper pairs. A superconducting phase controlled static magnetization and spin current are predicted as a result of such injection enabling a dissipation-less superconducting spintronics of superconducting point contacts.

**SELF-** **ASSEMBLED NANOFILAMENT TECHNIQUE**

**FOR POINT CONTACT SPECTROSCOPY OF SUPERCONDUCTORS**

**M. BELOGOLOVSKII, E. ZHITLUKHINA, M. GREGOR, T. PLECENIK**

*Department of Experimental Physics, Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava, 84248 Bratislava, Slovak Republic*

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This contribution is a summary of the main results obtained recently by the authors. Their goal was to develop a new *self-assembled nanofilament* methodology for creating metallic point contacts that utilize resistive switching effect in oxide films and can be considered as an experimental implementation of the well-known Blonder-Tinkham-Klapwijk (BTK) model. Within the BTK theory, gap-induced features in the differential conductance spectrum *G*(*V*) = *dI*(*V*)/*dV* of a device formed by normal (N) and superconducting (S) electrodes differ considerably for the two limiting cases, a sandwich-type N/I/S junction with a strong insulating (I) barrier and an ideal N/S bilayer with small scattering efficiency on the interface. The optimal experimental technique should be able to modify the interface transparency over a wide range thus measuring the same S sample in the two limits, for a perfect contact and in a tunneling regime.

The physical phenomenon behind the proposed approach is the resistive switching (RS) phenomenon ubiquitously found in simple and complex oxide-based heterostructures. In most cases, its underlying mechanism can be basically understood following the so-called conductive filament model in which the RS process is dominated by the formation/rupture of local conducting paths connecting terminal electrodes with sufficiently high electrical fields inducing a soft dielectric breakdown in the nanoscale oxide interlayer which sets the device to a conductive (low-resistive or ON) state.

The first experiments [1] performed on sandwiches with a TiO2 interlayer linking N and S electrodes showed that such samples can be repeatedly switched from high (OFF) to low (ON) resistive states by applying high enough voltage/current of opposite polarity. As a result, in the ON state, *G*(*V*) features in the near-gap region were fully consistent with those expected for an N/S bilayer. The RS tool applied to Nb, a conventional transition-metal superconductor, and the two-band/two-gap MgB2 superconductor allowed to reveal nonlinearities in the *G*(*V*) curves far above the energy gaps which were ascribed to the two modes, a point-contact regime without any significant barrier at the interface and the tunneling one [2]. The observed features were arising at energies corresponding to maximums in the phonon densities of states of Nb and MgB2 with amplitudes and general shapes reasonably agreed with theoretical predictions of the electron-phonon coupling theory in the superconductors. The next step [3] was associated with anomalous conductance dips at voltage biases slightly exceeding expected gap values. Using an RS experiment on a proximitized Al/Ni0.5Cu0.5/NbN system simulating the main features of the proposed explanation, it was shown that the unexpected dips arise for an inhomogeneous S state.

We believe that with some improvements, the self-assembled nanofilament methodology may provide a simple and promising way for advanced superconductor spectroscopy.

M.B. and E.Zh. acknowledge the EU NextGenerationEU financial support through the Recovery and Resilience Plan for Slovakia under the projects No. 09I03-03-V01-00139 and No. 09I03-03-V01-00140.

[1] M. Dvoranová, T. Plecenik, M. Moško, M. Vidiš, M. Gregor, T. Roch, B. Grančič, L. Satrapinskyy, P. Kúš, and A. Plecenik, AIP Advances 8, 125217 (2018).

[2] E. Zhitlukhina, M. Dvoranová, T. Plecenik, M. Gregor, M. Belogolovskii, and A. Plecenik, Appl. Nanosci. 10, 2617 (2020).

[3] S. Volkov, M. Gregor, T. Plecenik, E. Zhitlukhina, M. Belogolovskii, and A. Plecenik, Appl.Nanosci. 12, 761 (2022).

**point-contact spectroscopy of collective excitations in multiband proximity-coupled spin singlet-triplet frequency even-odd superconducting condensates**

**V. N. Krivoruchko, V. Yu. Tarenkov**

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Proximity-coupled nanostructures of conventional superconductors (SCs) and half-metallic ferromagnets (hmFs) are promising candidates for materials with spin-triplet superconductivity. The superconducting state in such heterostructures is characterized by the interrelated superposition of spin-singlet even-frequency and spin-triplet odd-frequency superconducting condensates. In a multi-band SC, the collective excitations associated with the relative phase oscillations between superconducting bands without perturbation of the Cooper pairs symmetry (Leggett modes) are allowed [1].

We present the results of experimental investigations by the point contact (Andreev) spectroscopy of collective excitations in proximity-induced three-gap superconducting state of the nanocomposite MgB2/La0.67Sr0.33MnO3 [2-4]. The exchange field breaks the time-reversal symmetry and the superconducting state in the SC/hmF nanocomposite is associated with the superposition of singlet/triplet-spin even/odd-frequency superconducting condensates [5]. Two types of point contacts (PCs) have been implemented: the nanocomposite - hmF (La0.67Sr0.33MnO3 and La0.67Ca0.33MnO3) PCs and the nanocomposite - nonmagnetic metal (Ag, Nb) PCs. Spin-dependent subharmonic structures were observed in the differential conductance dI/dV(V) of the PCs. The oscillation period of the conductance peaks for the nonmagnetic metal PCs was the same as earlier observed in MgB2 in transport measurements [6,7] and its origin has been attributed to the Leggett excitations from the ‘parental’ MgB2 σ- and π- condensates. The detected oscillation period for the nanocomposite - hmF PCs was *two times smaller*. We believe that the most likely reason for the decrease in the period observed in contact with hmF tip is inelastic emission/absorption of relative phase excitations between *triplet* condensates. To our best knowledge, this is the first direct observation of Leggett-like excitations in such systems. The transport characteristics of hmF PCs also indicate high-order coupling between *even* and *odd* frequency spin-triplet Cooper pairs in the MgB2/hmF nanocomposite and testify in favor of the existence of proximity-induced *odd-frequency* *gapless* pairing states in the MgB2/(La,Sr)MnO3 nanocomposites.

[1] A. J. Leggett, Progr. Theor. Phys. **36**, 901 (1966).

[2] V. N. Krivoruchko and V. Yu. Tarenkov, Phys. Rev. B **75**, 214508 (2007).

[3] V. N. Krivoruchko and V. Yu. Tarenkov, Phys. Rev. B **78**, 054522 (2008).

[4] V. N. Krivoruchko and V. Yu. Tarenkov, Low Temp. Phys. **49**, 847 (2023).

[5] I. I. Mazin, O. K. Andersen, O. Jepsen, O.V. Dolgov, J. Kortus, A. A. Golubov, A. B. Kuz’menko, and D. van der Marel, Phys. Rev. Lett. **89**, 107002 (2002).

[6] Ya. G. Ponomarev, S.A. Kuzmichev, M.G. Mikheev, M.V. Sudakova, S.N. Tchesnokov, N.Z. Timergaleev, A.V. Yarigin, E.G. Maksimov, S.I. Krasnosvobodtsev, A.V. Varlashkin, M.A. Hein, G. Müller, H. Piel, L.G. Sevastyanova, O.V. Kravchenko, K.P. Burdina, and B.M. Bulychev, Solid State Comm. **129**, 85 (2004).

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**ELECTRONIC DENSITY OF STATE IN HEAVY FERMION SYSTEMS**

**STUDIED BY POINT-CONTACT SPECTROSCOPY**

**MASANOBU SHIGA, TATSUYA KAWAE**

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Some rare earth compounds, referred to as Kondo lattice systems, exhibit fascinating phenomena, such as Kondo effect, heavy fermion behavior, unconventional superconductivity, and non-fermi liquid behavior due to the hybridization between conduction and *f* electrons (*c*-*f* hybridization) [1]. Theoretical studies show that the electronic density of state (DOS) in Kondo lattice systems varies owing to the evolution of *c*-*f* hybridization with decreasing temperature [2]. Below the Kondo temperature (*T* < *T*K), the Kondo resonance with a distinct peak structure forms near the Fermi level. Moreover, when the temperature is much lower than the Kondo temperature, the Kondo resonance splits into two peaks due to the development of the Kondo lattice coherence, where the peak separation between the two peaks reflects the hybridization gap formed near the Fermi energy due to the *c*-*f* hybridization.

According to the theoretical study on the electron tunneling process between a probe tip and Kondo lattice system in scanning tunneling spectroscopy (STS) measurements, the hybridization gap is expected to appear as an asymmetric double peak structure in the differential conductance (*dI*/*dV*) spectrum [3]. However, most STS measurements on Kondo lattice systems only observe an asymmetric dip structure in the *dI*/*dV* spectra, which is interpreted as a Kondo resonance. The discrepancy between the theoretical and experimental studies is considered to come from a low electron tunneling probability from the probe tip to the localized *f* orbital in STS measurements owing to a gap between the probe tip and sample. In other words, in the STS measurements, the low electron probability into the *f* orbital gives rise to the absence of the hybridization gap in the spectra. Therefore, another technique is needed to clarify the hybridized DOS on Kondo lattice systems. To this end, we focus on a point-contact spectroscopy (PCS) technique, where a probe tip touches the sample surface directly during the measurements. In the PCS measurements, when the contact size *d* is smaller than the electron mean free path *l* (*d* < *l*), the bias voltage dependence of the *dI*/*dV* spectra reflects the energy-dependent electronic DOS.

In the presentation, we introduce our recent PCS measurements on heavy Fermion systems CeRu2Si2[4] and EuNi2(P*x*Ge1-*x*)2[5-7]. In the CeRu2Si2, an asymmetric dip structure originating from the Kondo resonance is observed in the *dI*/*dV* spectra. Moreover, based on the theoretical fitting of the spectra, we show that the tunneling probability into the *f* orbital in our PCS measurements is larger than that in the STS measurements, indicating that the PCS technique is useful for exploring the hybridized DOS on Kondo lattice systems. In EuNi2(P*x*Ge1-*x*)2, an asymmetric double peak structure appears in the *dI*/*dV* spectra, which can be reproduced by the theoretical model [3], demonstrating the formation of the hybridization gap in EuNi2(P*x*Ge1-*x*)2. Furthermore, the magnitude of the hybridization gap and the Kondo temperature is decreased by the substitution of Ge atom for P site, demonstrating that the variation of the *c*-*f* hybridization can be traced using the PCS technique.

[1] A. C. Hewson, The Kondo Problem to Heavy Fermions (Cambridge University Press, Cambridge, 1993). [2] C. Grenzebach, *et al*., Phys. Rev. B **74**, 195119 (2006). [3] M. Maltseva, *et al*, Phys. Rev. Lett. **103**, 206402 (2009). [4] T. Takahashi, M. Shiga, *et al*., J. Phys. Soc. Jpn. **93**, 023704 (2024) [5] M. Shiga, *et al*., Phys. Rev. B **103**, L041113 (2021). [6] M. Shiga *et al*., JPS Conf. Proc. **38**, 011098 (2023). [7] M. Shiga, *et al*., Low Temp. Phys. **49**, 876 (202).

**POINT CONTACTS IN SPINTRONICS**

**M. TSOI 1,2**

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Point contacts - nanoscale electrical contacts between conductors - have been around for decades and proved to be unique experimental tools for studying the conductor’s transport properties [1-3]. In this talk, I will briefly review applications of point contacts in the field of spintronics, which studies the role played by an electron spin in solid-state physics and aims at the active control and manipulation of spins to be used in a revolutionary new class of electronic devices. Spintronics is built on a complementary set of phenomena in which magnetic configurations influence transport properties and vice versa. An example of the latter is the spin-transfer torque (STT) effect, which refers to a novel method to manipulate spins using an electrical current. Point contacts were instrumental for the first experimental demonstration of STT in magnetic multilayers [4], thanks to extremely high current densities routinely produced in such contacts. Other “first” demonstrations by point contacts include STT nano-oscillators [5] and STT in antiferromagnetic materials [6].

Point contacts have also been used to detect ferromagnetic resonance (FMR) [7] via spin rectification. Here a small dc photovoltage, which originates from the rectification of rf current in a ferromagnet with oscillating magnetization, is detected across the contact. We now study the role played by the contact in this rectification process. A system of four independent nonmagnetic contact probes was used to supply both rf and dc bias currents to a ferromagnetic (NiFe) wire and measure the resulting photovoltage at different locations in the wire. Our multiprobe system allows to separate different contributions to the photovoltage from (i) the ferromagnet/nonmagnet contacts and (ii) the bulk of the ferromagnet. The contact photovoltage was found to increase approximately linearly with the applied dc bias. In contrast, the bulk contribution was found to be almost independent of the bias. By tuning properties of individual contacts we were able to change the magnitude of the contact photovoltage and even reverse its sign. Our results highlight the different contributions to photovoltage and the importance of contact’s characteristics for rectification effects in spintronic devices.

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[4] M. Tsoi et al., Phys. Rev. Lett. **80**, 4281 (1998).

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[6] Z. Wei et al., Phys. Rev. Lett. **98**, 116603 (2007).

[7] T. Staudacher, M. Tsoi, J. Appl. Phys. **109**, 07C912 (2011).

**QUANTUM POINT-CONTACT SENSORS**

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In 2024, it has been 50 years since the discovery of the Yanson point-contact spectroscopy (Yanson PCS) [1]. Almost throughout the entire period of its existence, the Yanson PCS has demonstrated unique innovative opportunities to study a wide range of objects and phenomena [2]. At the initial stage of its application, the Yanson PCS and its techniques were developed exclusively in the framework of the low-temperature approach. However, after 2006, the temperature range of this technology has expanded significantly thanks to the discovery of the point-contact gas-sensitive effect [3]. These works have led to the creation of a new promising area of study and development of quantum point-contact sensors, which is rooted in the fundamentals of the Yanson PCS [4, 5].

The originality of the point-contact gas-sensitive effect came into light immediately after its discovery. It became obvious after the comparison of the characteristics of point-contact sensing elements and the parameters of the conventional sensors based on the principle of changing electrical conductance. The reason for this is easily understood: point-contact sensors were, in fact, the first example of quantum conductive sensors functioning at room temperature. Already in the first experiments, the sensing element of a point-contact sensor in the form of a Yanson point contact almost instantly showed not only its ultra-high sensitivity to the action of various gases, but also its ability to relax to the initial state in real time, even when dealing with such complex materials as carbon nanotubes.

The development of an innovative technology for creating unique sensing elements based on Yanson point contacts was made possible by the numerous “know-hows” of the Yanson PCS. The quantum nature of their electrical conduction became the basis for the discovery and study of new detection mechanisms that cannot be implemented in conventional sensors with the operation principle of changing electrical conductance [5]. This feature predetermined the universality of point-contact sensors and allowed using them to work with various media and objects.

In this report, we present a brief summary of the main aspects of the research into quantum point-contact sensing elements, methods for their creation, new quantum detection mechanisms discovered using Yanson point contacts, and some of the possible applications tested in real conditions.

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**POINT-CONTACT SPECTROSCOPY STUDY ON SUPERCONDUCTORS UNDER PRESSURE**

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In this talk, we will demonstrate that point-contact spectroscopy (PCS) can serve as a powerful tool to probe the superconducting (SC) order parameter under pressure, which has been successfully applied to study the kagome metal CsV3Sb5 [1] and semimetal MoTe2 [2] under pressure.

For CsV3Sb5 under pressure P<2.5 GPa, a multi-gap s-wave superconductor can be proposed with three distinct superconducting gaps observed. The smaller gaps Δ1 and Δ2 are robust under pressure, while the largest SC gap Δ3 can only be observed in the pressure range of (P1, P2) for soft-PCS along the c-axis direction, suggesting a complex relationship between charge-density-wave and SC.

Meanwhile, a first-order 1T'-Td structure transition can be monotonically suppressed by hydrostatic pressure until Pc ~1 GPa, accompanied by a rapid increase of superconducting transition temperature. The SC signal in G(V) curves under pressure shows a positive correlation with the reported Tc and volume fraction of the 1T' phase, supporting the probed SC for MoTe2 under pressure is intrinsic and mainly contributed by the 1T' phase. G(V) curves can be better fitted by a two-gap s-wave pairing for P<2.5 GPa in a strong coupling regime.

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**PRESSURE DEPENDENCE OF THE BCS RELATION ON TIN: IMPROVEMENT OF METHOD FOR POINT-CONTACT SPECTROSCOPY UNDER PRESSURE**

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Many fascinating superconductors have been discovered under high pressure in strongly correlated electron systems. Furthermore, some superconductors exhibit attractive pressure (*P*) dependences in their superconducting critical temperature (*T*c). To study the mechanism of *P*-induced superconductivity, developing a method to measure superconducting (SC) gap directly under pressure is necessary. The point-contact spectroscopy (PCS) is one of the most suitable techniques for high-pressure experiments.

We improved PCS measurement method for use under high pressures, wherein the point contact is directly fabricated on the sample surface using a platinum fine wire and an insulating adhesive lump. We observed temperature (*T*) variations of the point-contact spectra on the SC state of tin under given pressures. Figure 1 shows the *P* dependence of the spectrum at the lowest temperature of each pressure. It can be seen that the peak position shifts to the lower energy by applying *P*, indicating that the SC gap (*Δ*) becomes smaller. Measured spectra are well explained by Blonder-Tinkam-Klapwijk theory, which allows us to estimate the *T* dependence of *Δ* from each spectrum. *T* dependence of *Δ* for tin is consistent with the Bardeen-Cooper-Schrieffer (BCS) curve even under pressures up to 2.26 GPa, as shown in Fig. 2. It has been exhibited that the SC gap determined at the lowest measured temperature (*Δ*0) decreases gradually with increasing *P*, and the ratio between *Δ*0 and *T*c remains close to the BCS value with an error of less than 10% as well as under ambient pressure in the whole measured pressures.

This simplified PCS method for use under pressure is easy to use, and the feasibility of high-pressure PCS opens up new possibilities in the study of various materials, such as heavy fermion superconductors.

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**A MODEL FOR CRITICAL CURRENT EFFECTS IN POINT-CONTACT ANDREEV-REFLECTION SPECTROSCOPY**

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One of the fundamental requirements a normal/superconductor (N/S) point contact has to fulfill, in order to allow spectroscopic measurements of the superconducting energy gap, is that the bias voltage Vexp directly measures the excess energy of injected electrons [1]. This, in turn, requires that: i) the bias voltage Vexp coincides with the voltage drop at the interface, Vc, and ii) electrons acquire an excess energy eVc while crossing the contact region.

The first requirement can never be strictly fulfilled since Vexp is measured at the ends of a series of resistances [2], i.e. the one of the contact, Rc, and those of the two banks R1,2. While the resistance R1 of the normal bank (usually made of a metal) is generally much smaller than Rc and can be disregarded, the resistance R2 of the superconducting bank can play an important role (especially in thin films or 2D materials) when the current drives the superconductor to the resistive state. Since the critical current decreases with increasing temperature, this usually does not affect the conductance spectra at low temperature, but can bend their high-voltage tails and finally determine their overall downward shift when the temperature approaches *T*c [3,4,5].

The second requirement is equivalent to asking that electrons do not undergo inelastic scattering while crossing the contact region, i.e. the contact must be in the ballistic (or, at most, intermediate) regime [1]. Otherwise, a Maxwell term appears, that can be seen as a further resistance in series with the Sharvin one. This term contains the resistivity of the material, which can become nonzero when the current flowing through the contact reaches a critical value. As a result, typical dips appear in the Andreev spectra [6] that can prevent a reliable determination of the gap amplitude.

Here, we show that both these effects, due to the breakdown of the zero-resistance state in the contact region or in the bulk of the sample, can be modelled in the same way, i.e. by including in the equation for the differential conductance a current-dependent resistance (that mimics either the Maxwell term or the spreading resistance R2) in series to the “ideal” contact. We show that, using a proper model for this current-dependent resistance, obtained by fitting the experimental *R*(*I*) curves measured at different temperatures in Ba(Fe,Co)2As2 thin films [5], it is possible to reproduce the dips observed in point-contact experiments on completely different materials, as well as the effects of the spreading resistance in films and very thin crystals.

Finally, we show that the inclusion of the dips in the generalized BTK model allows fitting the experimental curves of non-ballistic contacts with impressive accuracy and with no need of normalization, and provides reliable gap values as well as information on the temperature dependence of the critical current.

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**FERROMAGNETIC JOSEPHSON JUNCTIONS: PROPERTIES FOR POTENTIAL APPLICATIONS IN QUANTUM CIRCUITS**

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We will report on special properties of hybrid Josephson Junctions (JJs), on how to engineer the macroscopic phase in quantum circuits, which make possible alternative layouts for the superconducting modules inside a more general architecture also through a comparative study of fluctuations and of electro-dynamical properties [1-5]. A special focus will be on junctions employing ferromagnetic barriers. Different types of ferromagnetic barriers give access to specific regimes. Our findings contribute to driving the design and the tailoring of S/F interfaces also in view of potential applications in quantum computing [1,6,7].

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**APPLICATION OF POINT-CONTACT SPECTROSCOPY IN THE STUDIES OF TOPOLOGICAL SUPERCONDUCTIVITY AND VORTEX DYNAMICS**

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Point-contact spectroscopy (PCS) was originally developed to study the elementary excitations within solid materials. Subsequently, it has been widely adopted to investigate superconducting order parameters, leveraging Andreev reflection that occurs at the interface between superconductors and normal metals. Additionally, PCS has become an essential tool in the search for topological superconducting materials. Especially in recent years, tip-induced superconductivity (TISC) has been detected on the surfaces of diverse topological semimetals, marking a new application domain for this classic experimental technique.

In this talk, we will present our findings on the local superconductivity induced at point contacts formed between metallic tips and a variety of topological materials. A fairly high critical temperature of approximately 12K was realized in the triple point topological semimetal, tungsten carbide, which intriguingly showed resilience to the magnetic influence of the tip [1]. In Weyl semimetal TaAs single crystals, two distinct superconducting phases were induced within two intergrown phases, displaying different temperature dependencies of the critical magnetic field Hc2(T), indicative of the predominant influence of bulk bands over surface states [2]. Within the MPn2 family-comprising TaAs2, NbAs2 and NbSb2, which possesses weak topological invariants, we observed a universal relationship between Hc2 (0) and Tc across different crystal orientations, further corroborating the principal contribution from bulk bands [3]. Tip-induced supercon-ductivity was also observed in the topological material grey arsenic [4]. The deduced temperature dependence of the superconducting gap, coupled with the anomalously elevated Hc2, suggests the potential realization of unconventional superconductivity. The inverse correlation identified between the superconducting gap and the effective barrier height Z implies that interfacial coupling may be a determinant factor in the observed TISC of topological materials. Building on these findings, we endeavored to deposit metal films on WC and TaAs single crystals, successfully achieving local interfacial superconductivity as evidenced by soft point-contact spectroscopy [5]. This approach offers a promising avenue for the exploration of elusive topological superconductivity and holds potential for application in topological-state-based spintronic devices.

In the last part, we will present a pioneering detection of local vortex motions by utilizing soft contacts with multiple parallel micro-constrictions [6]. This technique has been validated as a potential new method with high temporal resolution for studying vortex dynamics in type-II superconductors.

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**QUANTUM ANALOGUES OF DISSIPATIVE CIRCUIT ELEMENTS**

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Quantum analogs of nondissipative circuit elements, that is, structures that can exist in a superposition of states with different values of inductance or capacitance, are readily realized using, e.g., superconducting qubits. Here I consider the possibility of the existence of quantum analogs of dissipative circuit elements, which demonstrate superpositions of states with different resistances or memristances. Using the Landauer view of transport through a scattering barrier, I show that this leads to no contradiction with the dissipative character of these elements.

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**POINT-CONTACT ANDREEV-REFLECTION SPECTROSCOPY and MULTI-GAP SUPERCONDUCTIVITY in hydrogen-intercalated 1*T*-TiSe2**

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The transition metal dichalcogenide 1*T*-TiSe2 is not superconducting in the pristine state, but features a commensurate CDW phase below ≈ 200 K. When intercalated with various elements (Cu, Pd, Li) and molecules (diamine), or subjected to an applied pressure or an electric-field-induced charge doping, it becomes superconducting (SC) with Tc up to 4.15 K. However, the structure of the SC order parameter and its interplay with CDW order are still debated.

We recently demonstrated the possibility to induce a *new SC phase* in HxTiSe2 with Tc ~ 3.6 K by employing an electric field-driven hydrogen intercalation via the ionic liquid gating method [1]. By exploiting the stability over time of this phase, we were able to carry out many different transport and spectroscopic characterizations of the SC state [1, 2]. The bulk SC state appears already at very low values of x with a Tc that is almost independent on the H content and coexists with the CDW phase through most of the phase diagram. 1H NMR measurements in SC samples exclude a phase segregation between H-rich and CDW-ordered regions [2] while density-functional theory calculations show that SC arises from an orbital-selective filling of the Ti dz2 orbitals that produces a full reconstruction of the band structure [1]. These peculiar properties differ from those obtained in TiSe2 by charge doping, pressure, or other intercalations.

In order to understand the nature of SC in HxTiSe2, we recently studied the temperature dependence of the critical field and performed point-contact Andreev-reflection spectroscopy (PCARS) experiments down to 300 mK. The temperature dependencies of H//c and H//ab, suggest the SC phase to be multi-gap and quasi-2D, respectively, and very different from that observed in Cu- and Li-intercalated TiSe2 [3, 4].

In the present talk, I will mainly focus on the results of soft PCARS experiments at T between 300 mK and Tc and in a magnetic field H//c. They further indicate the existence of (at least) two gaps that may reside on different parts of the Fermi surface with different orbital characters. Their temperature and magnetic field dependencies, determined by using our recent model that introduces the critical current effects in PCARS, are quite different from what the two-gap BCS theory predicts. Also, the interpretation of the results of directional PCARS using small contacts is complex since they suggest the presence of an additional small order parameter.

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**IMPACT OF I. K. YANSON'S INVENTIONS ON ADVANCEMENT OF FIELD IONIZATION MASS SPECTROMETRY FOR MOLECULAR BIOPHYSICS PROBLEMS**

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In the early years of the formation of the Institute for Low Temperature Physics and Engineering, in the seventies of the last century, the founders of the institute in hunting for urgent scientific topics had turned their attention to the recent deciphering the structure of DNA (1953) by X-ray method. The opened by this discovery a highway for the adaptation of physical experimental techniques to studies of biomolecules and DNA in particular had inspired B.I. Verkin, I.K. Yanson and their coworkers to lunge in this direction, which resulted in “Interactions of biomolecules: new experimental approaches and methods” monograph [1].

In the course of the development of new approaches, I.K. Yanson had turned his attention to recent inventions of German scientists, related to point-contacts and tunnel effect subjects: field ion microscopy and field ionization (FI) mass spectrometry. The latter was introduced in his laboratory. FI at that time was practically the first “soft ionization” method which permitted mass spectrometric study not only of fragile biomolecules, but their intermolecular interactions (clustering) as well. The principle of FI of biomolecules is shown in the following scheme:



Harnessing of FI mass spectrometry permitted obtaining priority quantitative thermodynamic data on energies of the interaction of nucleic bases as the major DNA constituents [2]. These unique experimental data were employed as empirical parameters by the developers of the first quantum chemical methods of computer modeling of biomolecules. The data on ionization energies of nucleic bases are included in the database of the USA National Institute of Standards and Technologies. In the decades which follow the method of temperature-dependent FI mass spectrometry was applied to a wide range of DNA-related vital problems, namely hydration [3], the effect of chemotherapeutic anticancer agents, and nucleic acid-protein interactions. FI was further improved to the field desorption method which utilized the first nanotechnology of carbonaceous nanowhiskers growth and graphite flakes edges exposure [4].

The selection of the tunnel effect-based FI method was a scientific foresight of I.K. Yanson, since FI phenomena appeared to be involved in many other mass spectrometric methods developed by now, including electrospray ionization. The contribution of field effects can be separated into many desorption/ionization techniques, which utilize a wide range of nanostructured materials, such as surface-enhanced and graphite-assisted laser desorption/ionization mass spectrometry.

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**CURRENT-INDUCED SWITCHING IN ATOMIC-SIZE CONTACTS**

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Miniaturizing functional electronic devices remains a significant challenge and driving force in the field of nanoelectronics. Various concepts have been proposed for implementing binary logics in nanoscale devices. Here, we present a current-induced approach of driving controlled conductance switches in metallic atomic-size contacts made of mechanically controllable break junctions. Previous research has demonstrated the feasibility of realizing a non-volatile single-atom memory by applying voltage ramps on such a two-terminal device [1-4]. Based on recent theoretical investigations on current-induced atomic rearrangements in metallic nanocontacts, we suggest a vibration-mediated mechanism underlying this phenomenon, resulting in bistable atomic configurations [5, 6]. Depending on the current-biasing protocol, the experiments reported in [6] also reveal more complex switching patterns with material-specific probabilities and switching voltages, at which a conductance switch typically sets in. These include multi-level switches and also volatile memory states. Through a comprehensive statistical analysis, a variety of switching properties have been explored to gain more information on the stochastic nature of atomic-scale electromigration.

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**OBSERVATION OF ZERO-BIAS CONDUCTANCE PEAK ABOVE *T*C AT FeSe1-*x*Tex BY BREAK JUNCTION TECHNIQUE**

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The FeSe superconductor possesses the simplest crystal structure among the Fe-based superconductors [1]. This compound exhibits the superconducting critical temperature *T*c of 8 K at ambient pressure [1]. Furthermore, *T*c = 40-50 K is realized by applying pressure or intercalating between layers [2]. It was reported that in the monolayer FeSe film fabricated on the SrTiO3 substrate the *Tc* up to about 100 K was attained [3]. On the other hand, by substituting the Te atoms on Se sites, the *T*c of Fe(Se,Te) increases up to *T*c ~ 15 K [4], which is even higher than that of the bulk FeSe compound at ambient pressure.

Among several measurements investigating the *T*c enhancement in this compound, point contact spectroscopy with the control of the interface conditions demonstrated the 100% increase in *T*c for FeSe [5] as a prominent feature. Such *T*c enhancement by PCS is realized by approaching the surface from an infinite distance down to touch the metal. Apparently, alternative procedure exists by establishing the potential difference immediately after detaching the contact from the bulk crystal.

In this work, the junction conductance features of FeSe1-*x*Te*x* superconductors were investigated in the extended range of *x* ( 0 ~ 0.9) by break-junction spectroscopy at various temperatures. The measurements were concentrated on observing the *dI/dV*(*V*) spectra showing the characteristic peak structures at zero bias, where *I* and *V* denote current and bias voltage across the junction, respectively. Such characteristic peaks are due to the Josephson current and/or Andreev reflection occurring in the superconductor-normal metal-superconductor junctions. The zero bias-conductance peaks were observed ~ 5 - 6 K above the maximum bulk *T*c for any composition *x* except for 0 (FeSe) where the enhancement of *T*c was not observed. It should be noted that quasi-two-dimensional superconductivity, probably of the Berezinski-Kosterlitz-Thouless (BKT) type, was recently found at the interface between EuO and BaPbBiO3 oxides [6]. The emergence of such superconductivity always exists in thin layers with a large electron density of states, which may be realized in our case

These results strongly suggest that local superconductivity exists above the bulk *T*c that may be caused by the modified electronic structure due to the possible crystal strain on the surface of Fe(Se,Te) superconductors. Thus, one can obtain alternative information on the superconductivity induced at the fresh interface created by the break junction procedure.

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**ELECTRON-PHONON INTERACTION, MAGNETIC PHASE TRANSITION, CHARGE DENSITY WAVES AND RESISTIVE SWITCHING IN VS2 AND VSE2 REVEALED BY YANSON POINT CONTACT SPECTROSCOPY**

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VS2 and VSe2 have attracted particular attention among the transition metals dichalcogenides because of their promising physical properties concerning magnetic ordering, charge density wave (CDW), emergent superconductivity, etc., which are very sensitive to stoichiometry and dimensionality reduction. Yanson point contact (PC) spectroscopic study revealed metallic and nonmetallic states in VS2 PCs, as well as a magnetic phase transition was detected below 25 K. Analysis of PC spectra of VS2 testifies the realization of the thermal regime in PCs. At the same time, the rare PC spectrum, where the magnetic phase transition did not appear, shows a broad maximum of around 20 mV, likely connected with the electron-phonon interaction (EPI). On the other hand, PC spectra of VSe2 demonstrate metallic behavior, which allowed us to detect features associated with the EPI and CDW transition. For both compounds, the Kondo effect appeared, apparently due to the interlayer vanadium ions. Besides, the resistive switching was observed in PCs on VSe2 between a low resistive, mainly metallic-type state, and a high resistive nonmetallic-type state by applying bias voltage (about 0.4V). In contrast, the reverse switching occurs by applying a voltage of opposite polarity (about 0.4V). The reason for this may be the alteration of stoichiometry in the PC core due to the displacement of V ions into the interlayer under a high electric field. The observed resistive switching characterizes VSe2 as a potential material, e.g., for non-volatile resistive RAM, neuromorphic engineering, and other nanoelectronic applications. At the same time, VSe2 attracts attention as a rare van der Waals compound with magnetic transition.

The measured variety of PC spectra also testify about the strong dependence of electronic properties of both compounds on stoichiometry, induced vacancies, interlayer ions etc, which allows us to realize and observe different prospective ground states. On the other hand, the detection of the resistive switching effect using Yanson PCs [1, 2] opens an efficient and affordable method for the rapid search and characterization of materials that can be used to implement the latest technologies and develop more energy-efficient and flexibly scalable electronic devices.

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**SCANNING TUNNELING SPECTROSCOPY AND BREAK JUNCTION SPECTROSCOPY OF THE 2D LAYERED NITRIDE CHLORIDE SUPERCONDUCTOR **-TINCL AND THE RELATED MATERIALS**

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The layered nitride superconductors *M*NCl (*M*=Zr, Hf, Ti) constitute the peculiar class of materials, which possesses the maximum *T*c ~25.5 K. These superconductors contain two-dimensional (2D) conducting layers of rectangular lattice (**--type) or honeycomb lattice (** -type) of *M*N networks [1, 2].

Herewith we present the scanning tunneling microscopy and spectroscopy (STM/STS) and break junction spectroscopy (BJ) measurements for both superconducting **--Na*x*TiNCl (*x~*0.2, *T*c~18 K) and semiconducting *pristine-*TiNCl compounds [3].

The STM topography of both compounds showed rectangular atomic lattice patterns with a spacing of ~0.38 nm (= *a*0) and ~0.31 nm (= *b*0). The averaged differential conductance, *dI/dV*, curves of the superconducting **--Na*x*TiNCl show the superconducting gap value of 2 ~12 meV, yielding the gap to critical temperature ratio 2/*k*B*T*c ~7.7, while that of the *pristine*-TiNCl show no gap structure around this bias voltage region of several mV. The obtained characteristic ratio for **--Na*x*TiNCl (~7.7) resembles that found for various cuprate superconductors, reflecting the existence of common features of superconductivity in layered quasi-2D materials.

BJ spectroscopy measurements of the *pristine*-TiNCl demonstrate that *dI/dV* spectra reveal the gap structure with the energy scale of 4 = 180 meV vanishing at *Ts* ~ 120 K. Thus, the ratio of the gap Σ to the transition temperature *Ts* is 2*/kBTs*~ 10. Such a ratio is typical of the pseudogapping in cuprate superconductors and dielectric gapping in layered chalcogenides exhibiting charge-density waves.

Additionally, we will present the recent results of the BJ Josephson tunneling spectroscopy for the Bi-based cuprate superconductors.

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**A BRIEF HISTORY OF POINT-CONTACT SPECTROSCOPY IN KARLSRUHE**

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A sabbatical stay of Igor K. Yanson and his coworker A. I. Akimenko in early 1990s at the Physikalisches Institut of the former Universität Karlsruhe, today Karlsruhe Institute of Technology (KIT), was the kick-off for point-contact research activities at this location. Starting with studies of - at that time - highly fascinating high-temperature superconductors [1] the investigation of superconducting material stayed in the focus of the activities for more than a decade, in particular, measurement of the superconducting energy gap and its dependence on temperature, magnetic field and impurity doping. The technique makes use of Andreev reflection of charge carriers at the normal metal-superconductor interface to extract the gap parameter Δ.

While the first experiments utilized an experimental setup designed and fabricated at the B.Verkin Institute for Low Temperature Physics and Engineering in Kharkiv, Ukraine, a setup for point-contact experiments at ultralow temperatures was developed in Karlsruhe, which allows measurements in a 3He/4He dilution refrigerator down to temperatures below 50 mK. The extension of the temperature range for point-contact experiments into the mK-range opens the door to study also heavy-fermion superconductors and other unconventional superconductors with superconducting transition temperatures below 1 K [2]. For example, point-contact spectroscopy on the heavy-fermion superconductor UPt3 revealed the symmetry and nodal structure of the superconducting energy gap [3].

A new pitch came into the field with the development of nanostructured point contacts [4]. Electron-beam lithography is used to structure a nanometer-sized orifice in a free-standing insulating Si3+xN4−x membrane followed by metallization of both sides of the membrane in order to get a contact with well-defined orifice size. In contrast to contacts made by the needle-anvil and shear techniques, respectively, nanostructured point contacts offer high stability and defined contact sizes. Furthermore, a detailed characterization of contacts with respect to contact size and geometry, structure, and local electronic parameters allows a direct comparison of the measured point-contact parameters to different contact-size estimates [5].

Furthermore, nanostructured point contacts are studied to investigate the spin-dependent transport through superconductor-ferromagnet contacts [6]. Again, Andreev reflection is the key mechanism, now, to extract the spin polarization P of the transport current. The sensitivity of the Andreev process on the spin of the carriers originates from the conservation of the spin direction at the interface. Consequently, when there is an imbalance in the number of spin-up and spin-down electrons at the Fermi level, as it is the case in the spin-polarized situation of a ferromagnetic metal, this leads to a reduction of the Andreev reflection probability.

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**CHIRALITY INDUCED SPIN SELECTIVITY: AN OPEN PROBLEM IN SINGLE-MOLECULE JUNCTIONS**

***b***0

***a***0

**2 nm**

***a***0

***b***0

**2 nm**

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Already two decades ago, Ron Naaman [1,2] and collaborators demonstrated a surprising effect for electron transmission through a monolayer of chiral molecules: The chirality (left- or right handed structure) of the molecules produces a pronounced spin polarization for electrons that are transmitted through these molecules. The sign of the spin polarization is determined by the sign of the chirality. Even more surprising results appeared in later years, showing that the direction of the magnetization of a thin film is controlled by the chirality, and more. Such effects, collectively known as CISS (chirality controlled spin polarization) pose one of the most interesting and challenging problems in nanoscience. I will present a concise overview of the most important experiments, focusing on those experiments that have been done at the single-molecule level. I will discuss the fundamental questions these experiments raise, and to what extent partial answers have been formulated.

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**BASE ELEMENTS FOR SUPERCONDUCTING ARTIFICIAL NEURAL NETWORK**

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Energy efficiency and the radical reduction of the power consumption level become a crucial parameter constraining the advance of supercomputers. The most promising solution is the design and development of non-von Neumann architectures, first of all – the Artificial Neural Networks (ANN) based on superconducting elements. Superconducting ANN needs the elaboration of two main elements – a nonlinear switch (neuron) [1] and a linear connecting element (synapse) [2]. We present the results of our design and investigation of superconducting spin-valves and superconducting synapses, based on layered hybrid structures superconductor-ferromagnet.

Results of our theoretical and experimental study of the proximity effect in a stack-like superconductor/ferromagnet (S/F) superlattice with Co ferromagnetic layers of different thicknesses and coercive fields, and Nb-superconducting layers of constant thickness equal to coherence length of niobium, are presented.

The superlattices Nb/Co demonstrate a change of the superconducting order parameter in thin s-films due to switching from the parallel to the antiparallel alignment of neighboring F-layers. We argue that such superlattices can be used as tunable kinetic inductors for ANN synapse design [3].

The study was supported by the Project «Nanostructures and advanced materials for implementation in spintronics, thermoelectricity and optoelectronics » no. 020201.

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**NON-LOCAL AND POINT-CONTACT MEASUREMENTS**

**OF TRANSPARENT SUPERCONDUCTOR FILMS**

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Although superconductivity and optical transparency are generally considered to be mutually exclusive properties, a number of oxide compounds that are both transparent and superconducting have been discovered. Using doped indium-tin oxides (ITO) as an example, we analyze spectroscopic features of non-local and point-contact measurements revealing the origin of the superconductivity phenomenon in existing transparent oxides and design principles for new ones.

Large interatomic spacing in the bixbyite structure of indium-tin oxides () makes ITO favorable for the intercalation of small ions. The electrochemical processing of such films is a powerful method for tuning the physical and chemical properties of the base material whose structural evolution is expected to be more striking than that of bulk counterparts making it easier to explore new physics in the quantum limit. In our case, these techniques were applied to commercially available ITO layers with a thickness of about 350 nm. The pristine films did not show superconductivity down to 1.8 K. A control of the charge injection was performed by varying intercalation times at a fixed current of 0.1 – 1.0 mA/cm2 in an aqueous solution of 2 M NaCl or MgCl. Such treatment leads to the enhancement of superconducting properties from the critical temperature *T*c lower than 0.3 K for the parent compound to *T*c = 4 - 5 K. Powder X-ray diffraction was collected on a Bruker D8 Advance instrument with a Cu Kα (*λ* = 1.5406 nm) source. To improve the data collection, the stage was rotated at 5 rpm for each sample. Resistance-versus-temperature *R*(*T*) characteristics of the ITO films were measured using the van der Pauw combinations of current-carrying and voltage contacts. Point contacts on the ITO films were made by bringing a sharp metallic tip of silver in touch with the sample surface.

We have revealed a near-*T*c resistive peak in the *R*(*T*) curves for the sodium-doped films indicating huge heterogeneity of superconducting properties for relatively short intercalation times up to 500 s. Magnesium-doped films at 750 s doping time demonstrated improved uniformity of superconducting characteristics, probably due to the smaller cation radius of Mg2+ ions. The relatively sharp transition to the superconducting state and better homogeneity indicate on advantages of the magnesium ions intercalation. The differential conductance spectra *G*S(*V*) = d*I*(*V*)/d*V* of the point contacts with the latter samples exhibited zero-bias peaks well described by the well-known Blonder-Tinkham-Klapwijk (BTK) model with a comparatively large Dynes parameter. We note the presence of a pronounced dip in the differential conductance at the voltage bias *V* about 8 mV that cannot be adequately modeled using the BTK theory and is caused by an inhomogeneous superconducting state in the studied layer, conditionally divided into two parts with different gap values and a semitransparent potential barrier between them. Both findings indicate a noticeable heterogeneity of the ITO samples, which, after appropriate technological improvements, can form a basis of novel hybrid electronics integrating optical and superconducting components and thus avoiding significant losses due to photon absorption in the on-chip circuits. This applies to data transmission over optical fibers in a quantum network based on superconducting qubits and single-photon detectors.

The joint study of electrochromic metal oxides for transparent superconducting electronics was supported by the NATO Science for Peace and Security Program, project SPS G6082.

**KONDO SCREENING IN SINGLE ATOM CONTACTS OF TRANSITION AND RARE-EARTH MATERIALS**

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Using a Scanning Tunneling Microscope or the Mechanically Controlled Break Junction approach, both operated at 4K, we have demonstrated the Kondo Screening of the magnetic moment in one-atom contacts of the ferromagnetic transition metals, Fe, Co and Ni [1,2]. Here, using the same approach, we report our studies of the same effect for the rare-earth metals, Gd and Eu. Both metals having the same -f shell configuration while Gd has a d-electron which is absent for the case of Eu.

As in our previous work in transition metals, we find a zero-bias anomaly in the conductance curves that can be fitted to a Fano-Kondo line-shape, were different parameters, including the Kondo Temperature of the system, can be extracted. While in the case of Eu we find a similar distribution of Kondo temperatures as in our previous experiments, this time from the Kondo screening of a f-electron, surprisingly, in the case of Gd, we find a distribution around two different Kondo temperatures that we attribute to the two different electrons to be screened respectively of d- and f-character.

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**ATOMIC SIZE CONTACTS AND VISUALIZATION OF QUANTUM MATERIALS WITH VERY LOW TEMPERATURE SCANNING TUNNELING MICROSCOPY**

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In this talk I will introduce the technique of STM, discussing the differences between electronic transport in the single atom point contact and the tunneling limits. I will start by discussing a recent experiment on single atom point contacts of Au and Ag, where we have found spin dependent transport and a magnetic field induced modification of the jump to contact in magnetic fields of up to 20 T. Through a combined theory and experiment approach, this work shows the influence of adsorbed molecules on the quantum magnetotransport in nonmagnetic metals. I will then discuss the discovery of two-dimensional heavy fermions (2DHF) made of 5f electrons with an effective mass 17 times the free electron mass. These 2DHF present quantized states at terraces. The energy separation between quantized levels is of a fraction of a meV and the level width is set by the interaction with correlated bulk states [1]. Interestingly, we find a new connection between bulk and surface features, which shows that the surface can be used as a powerful probe to address pressing questions about electronic correlations, such as the hidden order problem of URu2Si2.

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