My research interests can be formally divided into three main domains: (1) **Mesoscopic Superconductivity**, (2) **Interface phenomena at Nanoscales** and (3) **Applied NanoTechnology**

Mesoscopic Superconductivity

Superconductivity is considered to be a collective phenomenon. Hence, one may ask a reasonable question: how large should be that 'collective'? At the same moment is it is known that role of thermodynamic fluctuations increases with decrease of a system dimensionality. The topic ofquantum fluctuations in quasi-1D superconductors, also called *quantum phase slips* (QPS), has attracted the significant attention [1]. We have shown that the phenomenon is capable to suppress the zero resistivity of ultra-narrow superconducting nanowires at low temperatures $T<<T_c$ [2-4] (Fig. 1) and quench persistent currents in tiny nanorings [5]. The coherent QPS effect enables fabrication of the new generation of quantum logic devices – qubits [6]. For more info - see our review [1].

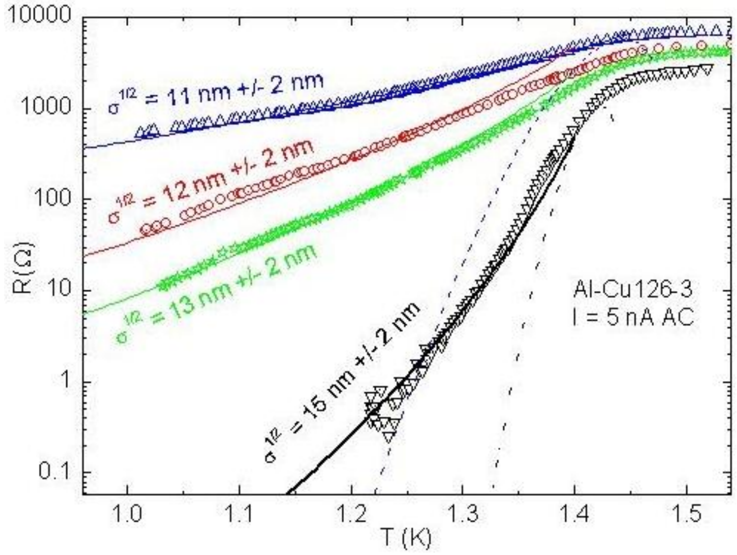

Fig. 1. Resistance vs temperature for several samples of the same Al nanowire obtained by progressive reduction of the diameter by ion milling. Thermal phase slip model fitting is shown with dashed lines for 11 and 15 nm samples.QPS model fittings are given with solid lines [3].

Of our current interest is the topic of fundamental importance: quantum duality of QPS and Josephson effects. The observation leads to an intuitively controversial result: sufficiently narrow superconducting nanowire, imbedded in high-impedance environment, enters an insulating state [7]. Such system can be considered as a junctionless single electron transistor (with charge *2e*), where the QPS provide the dynamic equivalent of weak links in conventional devices containing static (in space and time) Josephson junctions. Application of external RF radiation can be synchronized with the internal charge oscillations leading to the long-awaited metrological application - the quantum standard of electric current [8].

[1] K. Yu. Arutyunov, D. S. Golubev, and A.D. Zaikin, ***Phys. Rep.*** 464, 1 (2008).
[2] M. Zgirski, K.-P. Riikonen, V. Touboltsev, and K. Arutyunov, ***NanoLett***. 5, 1029 (2005).
[3] M. Zgirski, K.-P. Riikonen, V. Touboltsev and K.Yu. Arutyunov, ***Phys. Rev. B***. **77**, 054508 (2008).
[4] J. S. Lehtinen, T. Sajavaara, K. Yu. Arutyunov, M. Yu. Presnjakov and A. Vasiliev, ***Phys. Rev. B*** 85, 094508 (2012).
[5] K. Yu. Arutyunov, T. T. Hongisto, J. S. Lehtinen, L. I. Leino, and A. L. Vasiliev. ***Nature: Sci. Rep.*** 2, 293 (2012).
[6] O. V. Astafiev, L. B. Ioffe, S. Kafanov, Yu. A. Pashkin, K. Yu. Arutyunov, D. Shahar, O. Cohen, & J. S. Tsai, ***Nature*** 484, 355 (2012).
[7] J. S. Lehtinen, T. Rantala and K. Yu. Arutyunov, **arXiv-1311.3202** (2013).
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Interface phenomena at nanoscales

With natural tendency for further miniaturization of electronics components, interface phenomena are of crucial importance. It might easily happen that the whole nanostructure, being smaller than the characteristic non-equilibrium relaxation length, is an ‘interface’. Apart from purely academic interest, performance of a new generation of hybrid nanodevices (e.g. molecular nanoelectronic components) requires knowledge of the details of electron current conversion at the interface.

Of particular interest is the conversion of the normal electron current into the supercurrent in nanoscale hybrid systems. The effect can be studied in experiments with injection of non-equilibrium excitations into a superconductor from the normal metal at ultra-low temperatures (Fig. 2). The results show anomalously large scales at which the non-equilibrium quasiparticles relax: ~5 um for charge imbalance and >40 um for energy relaxation).]. For more info - see [9].

The study is of fundamental importance for basic science and for numerous nanoelectronic applications. Utilization of a ferromagnetic electrode as ‘spin injector’ is expected to increase significantly the corresponding relaxation times (lengths) due to necessity to equalize the spin-up and spin-down quasiparticles to form an equilibrium Cooper pair.

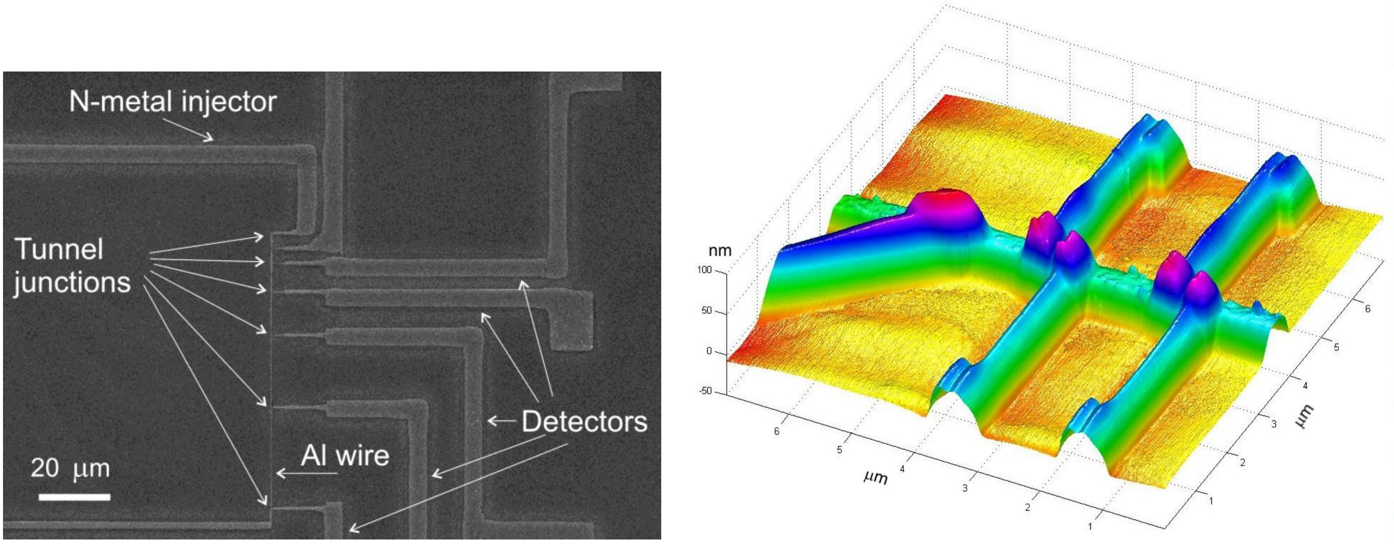

Fig. 2. SEM and AFM images of the structure [9].

[9] K. Yu. Arutyunov, H.-P. Auraneva, and A. S. Vasenko, **Phys. Rev. B** 83,104509 (2011).

Applied NanoTechnology

We have developed the method of non-destructive progressive reduction of dimensions of pre-fabricated nanostructures based on low energy ion beam milling. The method enables reproducible fabrication of nanostructures with sub-10 dimensions: e.g. ultra-narrow nanowires [10] or ultra-small single-electron transistors (SETs) [11]. The method is useful for various research projects where some size phenomena are to be studied. Two patents were obtained [12]. The downscaling of a nanostructure is accompanied with polishing of the surface down to +/- 1 nm roughness (Fig. 3).

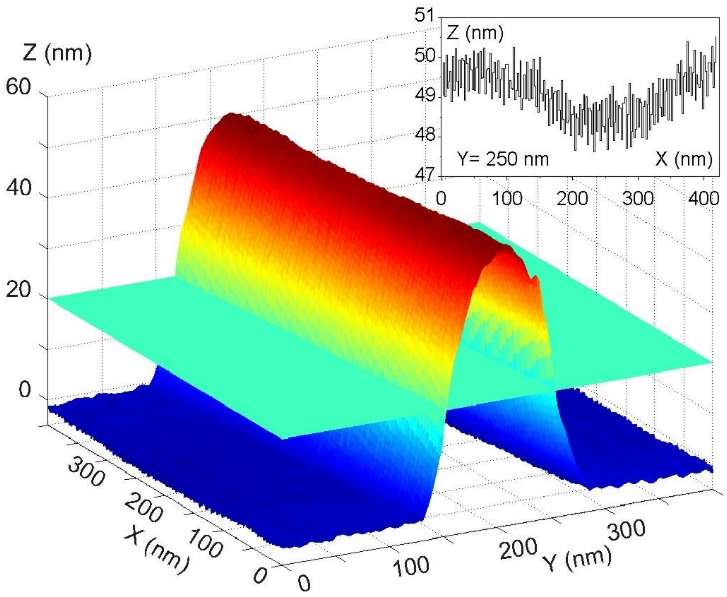

Fig.3. SPM image of typical part of a titanium nanowire after ion beam polishing. Horizontal plane indicates the interface between the metal and the sputtered Si substrate. Inset: AFM measured profile of the top surface [13].

The method appeared useful for certain ‘low-tech’ application as super-fine polishing of various surfaces, where other methods are either non-applicable, or are not precise enough. Our team is involved in several industrial projects, where our partners want us to polish the surface of cutting machine tools and/or gears with (sub)-100 nm accuracy (Fig. 4). An extra feature might be implantation of particular ion species making the surface harder and/or durable.

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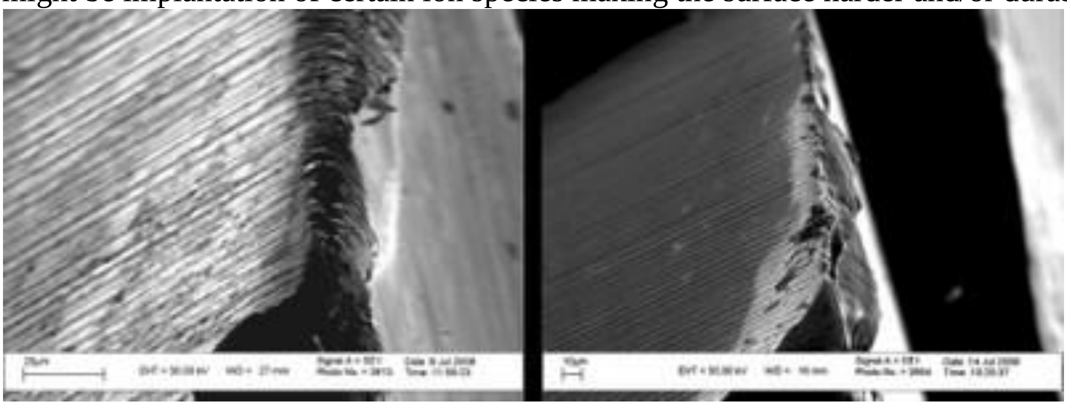

Fig. 4. SEM images of the cutting edge of a high-speed drill. Left panel: conventional new drill. Right panel: same tool after ion beam polishing [unpublished].

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[12] K. Yu. Arutyunov, Ion beam etching method and ion beam etching apparatus, **patent** FI-122010; K. Yu. Arutyunov, V. Tuboltsev and M. Kaarre, **PCT patent** FI-2007/050440, WO 2008/017733 A.

[13] J. S. Lehtinen, T. Sajavaara, K. Yu. Arutyunov, M. Yu. Presnjakov, and A. L. Vasiliev, **Phys. Rev. B** 85**,** 094508 (2012)