BERNARD BARBARA

XAVIER BLASE

YURIY BUNKOV

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A. Joannides Prize 2007
GP Gentner-Kastler 2007

Silver Medal 2008

Fritz London Prize 2008

CNRS Crystal 2007
Foreword

All scientists were delighted to see Albert Fert and Peter Grünberg receive the 2007 Nobel Prize for Physics in Stockholm. This award has had a tremendous impact on policy makers, recalling every day of this turbulent year how a discovery made in a risky topic started 30 years ago has led to “a technology able to miniaturize hard disks useful for everyday life.”

There was a gap of 20 years between the breakthrough publications and the Nobel awards, a gap of ten years between the ideas originated then and the first reading-heads based on the discovery of GMR (giant magneto-resistance), and there have been a huge number of subsequent, now flourishing ideas thanks to convergence between the nanotechnologies and the rapidly growing field of spintronics.

It is that time scale of ten years that must be emphasized: a time, moreover, quite short compared to the usual delay between a scientific discovery and a marketable device, and yet a delay only reluctantly accepted by policy makers. It is just as crucial these days to recall the unique capability of the CNRS in having built a joint laboratory with the Thales (previously Thomson) company in only six months, more than 20 years ago. And the world-wide recognition of physicists working in CNRS laboratories cannot be explained if one denies the efficiency of the network based on these laboratories, with their orientation to excellence.

A consequence of the CNRS’s great strengths is that its laboratories – including the Néel Institute – are attractive to foreign physicists. Thus, Yuriy Bunkov came to Grenoble in 1992 from Moscow’s Kapitza Institute, and was appointed permanently as a Director of Research at the CNRS-Grenoble in 1995. It is a unique honor for each member of our laboratory to congratulate Yuriy Bunkov, who will receive the Fritz London Memorial Prize this August at the Low Temperature Physics Conference in Amsterdam.

This prestigious prize is to be awarded for the discovery of “spin superfluidity” and related phenomena. The phenomenon of spin superfluidity shows a current of spin (magnetization) behaving as an analogue of both superfluidity (a current of mass) and superconductivity (a current of electric charge). The Grenoble group has published some 25 articles on this subject. Among the 16 most cited papers, 10 come from Yuriy’s Grenoble period, some of them linked to the Grenoble-Moscow collaboration.

We are delighted to add three other names to the awards board for this year. Xavier Blase, who joined our laboratory recently after a scientific itinerary working with Steven Louie at Berkeley, with Roberto Car at EPFL and with J-Louis Barrat at Lyon, has won a Silver Medal of the CNRS for 2008 (see article inside). Bertrand Menaert has won a Crystal Medal of the CNRS for his exceptional creativity in the growth and machining of laser crystals, yielding two licensed CNRS patents. Bernard Barbara has been honored twice, as the recipient of the Grand Prix Alexandre Joannidès of the Académie des Sciences and the Gentner-Kastler Prize of the DPG and the SFP for 2007.

The next issue of the Néel Institute Highlights will give further scientific information relevant to these prizes in the context of our laboratory.

The present issue of Highlights features the observation of a new phenomenon in spintronics – a quantum phase transition in a molecular scale transistor – achieved by inserting a C_{60} molecule between two nano-machined electrodes, part of a nano-squid. Two electrons brought into this molecule form a singlet state (no magnetic moment) or a triplet state (with magnetic moment), depending on the electric field produced by a gate. The paper published in Nature (May 2008) increases the number of publications in Nature(s) and Science to 11 for this last year and a half.

Last but not least, we must emphasize the exceptional expertise of the technology “poles” and services of the Néel Institute, providing outstanding support to the Institute’s staff in meeting their experimental challenges and in their commitment to international collaboration/competition. In this issue, we present one such achievement, with transfer to industry. A total of about fifty of our EPC1-B preamplifiers, optimized for the measurement of very low voltage signals from high impedance sources, have been built in-house and are currently used throughout the Néel Institute. Their industrialization has now been launched by the Celian-CE3M company under license from the CNRS.

Grenoble June 29, 2008

Alain Fontaine

Director of the Néel Institute
The Department of Condensed Matter and Low Temperatures conducts fundamental studies of new states of matter (magnetism, charge density waves, superconductivity, etc.) and of the physics of helium between 100 μK and room temperature. The department develops transverse activities in cryogenic electro-technology, fluid mechanics, astronomy, the life sciences and associated applications (cryogenics, aero-space).

The Department of Nanosciences is engaged in the study of the physical properties of nanostructures: electronic transport, magnetism, nanomechanics, spectroscopy... at both experimental and theoretical levels. These nanostructures are prepared from various types of materials chosen for their specific properties - novel semiconductors, superconductors, metals, magnetic materials and molecules... Their fabrication at the nanometre scale - molecular films, nanowires, nanotubes, quantum wells and dots - leads to novel functions resulting from the most fundamental aspects of quantum physics.

The Department of Condensed Matter, Materials & Functions fosters fundamental research of materials and their applications. It has wide range experimental and theoretical expertises in material preparation, crystallography, electronic structure, magnetism, lasers, non-linear optics, catalysis and energy. The Department is distinguished by a strong interplay between physics and chemistry. It manages national projects at the ESRF and ILL and coordinates two thematic networks of the CNRS.
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Yuriy Bunkov, London prize 2008

The London prize will be awarded at the international conference on low temperatures and physics of the hehelium in Amsterdam, August 19-20, 2008. Yuriy Bunkov will receive a prize with Vladimir Bragin from the Kapitza Institute in Moscow, Russia. The prize will be given for the demonstration of phase coherence between vortices in dilute helium-II. This is a significant advancement in the field of low-temperature physics and has important implications for the study of superfluids.

Since the discovery of phase coherence, researchers have observed many interesting phenomena, such as the spin-liquid state in high-energy systems, superfluidity in dilute helium-II, and the formation of vortices in dilute helium-II. These phenomena have paved the way for new technologies in the field of low-temperature physics. The London prize recognizes the importance of these discoveries and the impact they have had on the field.

Yuriy Bunkov's research interests include condensed matter physics, particularly in the areas of superfluidity and superconductivity. He has made significant contributions to the study of low-temperature physics and has been recognized for his work in this area.

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The London prize, given once every three years, is named after Fritz London, an influential scientist who made significant contributions to the field of quantum mechanics. The prize recognizes outstanding contributions to the study of superfluidity and superconductivity.
In some materials, the charge density wave (CDW) acquires a spatial modulation below the transition temperature $T_c$, known as the Peierls transition, specifically in quasi-1D materials. In similar phenomena involving the spin density wave, spatial modulations in the spin density wave along the chain(s) in both cases are described by the period, amplitude and phase.

In general, material modulation does not have a constant phase over the entire material, because defects and disorder introduce pinning centres which affect the amplitude and the phase of the modulation locally. Hence, the phase of these modulation results from a compromise between the elastic energy that penalizes large phase gradients and the pinning energy that tends to fix the phase at the strongest pinning centres. These two ingredients produce metastable states as the result of collective pinning. Collective pinning, however, becomes frozen below 0.05 K, and a glass-type order transition is shown by dielectric susceptibility experiments at very low temperatures. The residual degree of freedom appears to be local defects in the strong-pinning model.

Larkin and Ovchinnikov have shown that a single strong-pinning impurity lead to a bound state at the Fermi level and an electron-like soliton and a hole-like antisoliton. This results in an insulator-$\sigma(\psi t)$ with multiple minima, leading to slow relaxation processes that depend on the low-temperature behavior of the CDW relaxation observed in various experiments.

In equilibrium, the quasi-one-dimensional compound TMTTF$_2$Br$_x$ has a spin-density ground state which is commensurate with the lattice periodicity. When a sufficiently large magnetic field is applied, the heat relaxation experiments provide evidence that the ground state no longer has the same symmetry. The experiments are interpreted using the local model of a strong pinning and the confinement of the soliton-antisoliton pair by the Zeeman coupling of the spin degrees of freedom. This results in a magnetic-field-induced density-wave glass for the spin carrying the phase configuration.

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**Further Reading**
Interlayer tunneling spectroscopy of charge density wave subgap states

One signature of strong electron correlation is symmetry broken state, such as charge and spin ordering in superconductivity. At the phase that results from symmetry breaking, the basic electronic properties are profoundly modified.

The elasticity of broken symmetry ground states allows extra electrons to be accommodated by local deformation of the ground state wavefunctions, whatever the mechanism used to add electrons (doping, pumping in injection). Because of the ground state degeneracy, the local modifications can be viewed as the formation of topologically nontrivial configurations, in particular, solitons. Experimentally, the presence of solitons was identified by conducting polymers such as polyacetylene (2000 Nobel Prize in Chemistry) where spin charge carriers carrying solitons appear under doping, optical pumping and charge injection.

In layered electronic materials, perpendicular transport occurs by tunneling between elementary conducting layers at the nanometric thickness. Recently, the method of intrinsic coherent tunneling has been developed for high $T_c$ superconductors, and has been applied to layered materials having a charge density wave (CDW) ground state.

Like the superconducting state, the CDW ground state corresponds to an electronic condensate opening a gap at the Fermi surface. However, the CDW condensate is spatially modulated and coupled to the lattice distortion thus forming an electronic crystal resembling a single-electron-like pairs of electrons.

Many charge density wave materials, such as NbSe$_2$, TaS$_2$, TaSe$_2$, etc., are formed from elementary conducting layers assembled by conducting layers and separated by insulating layers, facilitating tunneling spectroscopy. Investigations by this new technique have been advanced by the development of sub-micronized stacked structures fabricated by means of focused ion beams, and by artificial double layer junctions structures in NbSe$_2$.

Advanced interlayer tunneling techniques, having very high resolution, provide a wealth of possibilities for probing amplitudes and phase excitations of the uniform CDW ground state. The energy of both types of excitations is inside the CDW gap $\Delta_3$, thus they can contribute to the interlayer tunneling in the ungapped carriers. Conventional tunneling techniques could not resolve these pntraphotoemission states.

We have reported recently the first direct observation of microscopic solitons in single electronic processes, including a detection of the interband tunneling across the gap $\Delta_3$. An unexpected strong peak was seen at the intermediate voltage $2\Delta_3/3$ (Fig. 3), this peak is associated with the creation of microscopic solitons, as predicted. These solitons might correspond to the long sought special quasi-particle like spinon. Tunneling can go through the soliton channel, solitons being more favorable than quasiparticles in this channel.

The phase solitons are associated with formation of dislocation lines in the CDW phase (CDW phase vortices). The energy of dislocation line in the border of the Peierls transition temperature $T_p$ that is about 1 $\Delta_3$ the phase solitons can be created by an electric field applied on the stacked junctions. Their formation requires a threshold energy $\Delta_3/2$ $\Delta_3$. (Fig. 1). Particularly astonishing is the clean observation of staircase staircase structure in the tunneling spectrum near to entry of the CDW charged dislocations through the aggregate of charged phase solitons above the threshold voltage $\sqrt{2}\Delta_3$. Note the remarkable similarity between layered superconducting and CDW systems that manifests itself in similar mechanisms of phase decoupling, dislocation lines, and vortexes. In both cases the threshold energy for phase decoupling is associated, with $T_p$, much smaller than the energy gap.

Fig. 3. Interlayer tunneling spectrum in NbSe$_2$ at 00K showing the singularities at 2$\Delta_3/3$ (gap) and $\Delta_3$ (creation of microscopic amplitude solitons), and $\Delta_3$ at 2/3 $\Delta_3$ (formation of dislocation lines from vortices decoupling).
Very low noise differential preamplifier

The Neel Institute has a well-established record for transferring its expertise in instrument technology to industry. The latest example of a preamplifier with exceptional specifications, the EPC-1-B, is optimized for very low voltage signals from high impedance sources such as those encountered in low temperature measurements. This instrument is now distributed by the company Célians-C3EM under license from the CNRS.

The EPC-1-B pre-amplifier was developed in-house for high sensitivity, high precision and low temperature measurements. High protection against perturbations. Compared to pre-existing preamplifiers, the noise level is reduced by a factor of 10. This translates, for example, into a reduction by a factor of 10 in the time required for a slow measurement.

The EPC-1-B is characterized principally by a low noise level, high input impedance and its very high gain. The novel circuitry gives a very low input resistance while maintaining excellent noise performance.

The general field of application is accurate measurements at high sensitivity. The EPC-1-B is especially useful for amplifying signals coming from high input impedance such as piezoelectric sensors, accelerometers, microphones, pressure sensors... or capacitive sensors.

Before their industrialization, about 50 of these amplifiers were built internally and they were being used throughout the Neel Institute.

Characteristics:
Gain values: 0°, 0°, 0°, 0°
Manual adjustment by TTL signals;
F_{min} = 500 MHz; F_{max} = 300 kHz;
Z_{in} = 200 Mohms; 0 pF;
common mode rejection: 10 dB from 100 Hz to 50 kHz.

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Fig. 1. The EPC-1-B in photo-coupled balanced differential preamplifier.

Fig. 2. Noise voltage of the EPC-1B configured with a gain of 100.

26.2°C
-40.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
Frequency (Hz)

Gain (V/Hz)

0.1
1.0
10.0
100.0
1000.0
Nanofluids are liquids that contain small volumetric fractions of nanoparticles. These substances often exhibit unique properties without problems related to clogging and sedimentation. Here, the rheological properties of colloidal nanofluids are observed by passing them through microchannels.

The viscosity of nanofluids has been studied because of its much lesser extent than their thermal conductivity. However, controlling the viscosity of liquid suspensions is important in diverse areas ranging from biotechnology to design of miniaturized heat exchangers. The dynamic viscosity of nanofluids is not well understood, especially the relative effects of the size of the nanoparticles and of the volume concentration compared to monodisperse particles. Nanofluids are subjected to colloidal interactions enhanced by Brownian motion and hydrodynamic interactions. The competition between these effects is characterized by the dimensionless Péclet number, $Pe \approx \frac{\eta_0 \nu}{k_B T}$, where $\eta_0$ is the viscosity of the base fluid, $\nu$ is the particle diameter, and $k_B$ is the Boltzmann constant.

However, reaching high $Pe$ values with nanosized particles is an experimental challenge because $\nu$ is very strong and heat flow rates that are necessary and hardly attainable with conventional rheometers.

We have designed capillary microviscometers based on microchannels with integrated local pressure and temperature probes. To directly measure the hydrodynamics of monodisperse silicon dioxide nanofluids, we designed a micrometer-scale high-concentration height with $d < 50$ nm. In the channels, the relative viscosity of each $Pe$ value is about $2 \times 10^5$, while retaining linear behavior.

An anomalous enhancement of the viscosity has been observed with increasing volume concentration. This explanation is that the strong heating forces in the microchannels affect the viscosity of the agglomerates. The effects of these interactions are most pronounced for large nanoparticles owing to higher $Pe$ values. The hydrodynamics of agglomerates are in a regime to reduce effective volume concentration. As a consequence, the relative viscosity is lowered. The aggregation of particles may be hindered by a strong heating function. Very high heating rates in microchannels appear to be a way to make nanofluids converge to well-defined rheological values.

This work has been highlighted in Nature Nanotechnology as a landmark contribution to the year.

**Fig. 1.** Transmission electron microscopy image of an ensemble of $SiO_2$ particles. The circles of 0.01 μm diameter indicate the typical particle size.

**Fig. 2.** Evolution of the relative viscosity of $SiO_2$ nanofluids as a function of the volume concentration. The anomalous enhancement of the viscosity and the particle-size effect are consequences of both agglomerate size and hydrodynamic interactions. The viscosities of nanofluids are above the classical fluid $\eta_0$ for nanosized particles.

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**Further Reading:**  
Model systems for high-velocity domain wall propagation

Domain walls in narrow strips of ferromagnetic materials have been proposed as carriers of information. The information could be transmitted through the external magnetic field, electric current, or by the so-called spin-torque effect. Information could be transported and processed along domain walls propagated along complex networks of narrow magnetic strips.

Under given experimental conditions (temperature, magnetic field, current density, voltage), the velocity of propagation of domain walls depends on both extrinsic parameters and intrinsic parameters. The extrinsic parameters are related to the geometry of the system (size, shape, roughness, and defects), while intrinsic parameters are related to material characteristics such as saturation magnetization, spin polarization of the conduction electrons, and magnetic anisotropy.

Better control of such parameters should allow optimization of domain wall velocities in view of using them as rapid and versatile carriers of information. For this purpose, we have chosen to develop model systems where we have several extrinsic and intrinsic parameters that can be tuned independently.

We have recently demonstrated a method for tuning the orientation of thin-plane magnetic domains and domain walls in narrow ferromagnetic strips of cobalt by manipulating an intrinsic system parameter, the magnetic anisotropy. This is achieved by inducing a uniaxial in-plane anisotropy in a controlled way using oblique evaporation and direct correlation between the imposed direction of magnetization and the domain orientation. We have achieved this experimentally and confirmed by micromagnetic simulations. The domain walls in the strips are always oriented along the oblique evaporation-induced easy axis, irrespective of the in-plane anisotropy.

The inclined orientation of the domain walls in the figure, although surprising, was shown to be advantageous for the strip's characteristics. Perpendicular to the strip's plane, this would minimize the length, thereby reducing the total exchange energy. However, a parallel orientation was not obtained experimentally. Nevertheless, in the simulations, We have shown that the inclination of the domain wall to the magnetic field effects the compensation of the positive and negative magnetic volume changes.

Further reading:

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Artificially-induced inclined domain walls

Spin structure of an inclined Néel wall

Figure 9: Top: Magnetic Circular Dichroism, Photoelectron emission microscopy, and Magnetic Force Microscopy (MFM) images of a magnetization direction in the domains. Thus, the static and dynamic properties of domain walls can be altered by controlling the wall orientation.

Extensive studies of domain wall propagation and dynamics are being done at the international Nanomagnetism group. The following model systems such as magnetic multilayers, epitaxial systems, and nanomagnonic imaging have been investigated. (Top view)
Coupling two superconducting circuits

The operation of microelectronics circuits is described by the classical laws that prevail in the macroscopic world. These laws are profoundly changed for phenomena occurring at the atomic scale. The world of atoms and molecules is determined by quantum mechanics. Superconducting circuits provide the bridge between these two worlds. These electronic circuits are macroscopic in scale but obey the laws of quantum mechanics. They constitute models for treating, analyzing, and testing new properties of the domain of quantum electronics.

We have studied a circuit consisting of a Cooper pair of transistors arranged in parallel with a SQUID—the superconducting loop—containing a small Josephson junction. The transistors are small superconducting islands connected to the external circuit by two Josephson junctions. Depending on the value of the applied grid voltage, this box can contain either zero or two Cooper pairs of electrons. The transistors are thus controlled between two different quantum states designated by $|\uparrow\rangle$ and $|\downarrow\rangle$ and constitute a quantum bit, called a charge qubit. The SQUID is a strongly nonlinear resonator. This resonator can contain zero or one elementary excitations called plasmons, giving states of electronic degeneracies labeled by $|0\rangle$, $|1\rangle$, and $|\uparrow\rangle$. It constitutes a second quantum bit, called a phase qubit, which is controlled by an applied magnetic field and by the current flowing through the loop.

We have measured the transition probability between the coupled ground states $|0\rangle$ and the excited states $|\uparrow\rangle$ and $|\downarrow\rangle$ as a function of the frequency of an applied microwave field applied to the transistors grid and of the SQUID. These measurements provide the energy spectrum of the coupled circuits as a function of the external control parameters (grid voltage, magnetic flux through the SQUID). The frequency of these resonant transitions between the levels is about 100 GHz and corresponds to energies of about 0.2 meV. The experiments are done in dilution cryostats ($T \sim 50 \text{mK}$) to avoid thermal population of the excited states.

When the energies of the two qubits are equal, their coupling lifts the electronic degeneracy and produces anticrossings in the energy spectrum. The states of maximum entanglement are then achieved. With our circuit, we have observed controllable entangled states between the two qubits. We have obtained a detailed description of the energy spectrum as well as the coupling using a quantum mechanical model. Thus, a manipulation of the entangled states and the quantum information is now possible with superconducting nanocircuits.

![Energy spectrum and the coupled circuit.](image)

**Fig. 2.** Energy spectrum of the coupled circuit as a function of the grid voltage. Shelling of the degeneracy $|\uparrow\rangle = \frac{1}{\sqrt{2}} (|0\rangle + e^{i\phi}|1\rangle)$ is visible in the coupling strength between the two qubits. Quantum theory without coupling (dotted lines) and with coupling (continuous curves).

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**Further Reading:**
Graphene consists of a flat plane of carbon atoms arranged in an unconvoluted two-dimensional structure with properties that appear more and more fascinating to researchers. The fact that it can be grown on silicon carbide substrates holds high promise for device applications in nano-electronics. However, it is essential to establish whether the remarkable properties of graphene are retained on a system of carbon planes in close proximity to a substrate. We have addressed this question by a combination of scanning tunnelling microscopy (STM) measurements and ab initio calculations on the electronic structure.

The key to the quite exceptional electronic properties of graphene lies in the symmetry of its crystal structure. The unit cell consists of two strictly equivalent carbon atoms, yielding six new degrees of freedom compared to other 2D systems. The question of how this symmetry is retained in the form of a graphene plane in contact with a silicon carbide surface or with another plane of graphene?

Since 2006, the Blue Institute has been applying its expertise in materials science and the growth of graphene on silicon carbide substrates, starting from a method originated by W. Heer and C. Berger. The steady scission of hexagonal single crystal layers from around 200°C ultra-high vacuum (UHV) control can be carried out in quite accurately plane-by-plane graphene produced on the case of a single plane (Fig. 3(a)). The STM images show an equivalent contrast of all carbon sites, as expected for a graphene plane on an example of a clean interaction with its environment. Note that the images also show long-distance modulation induced by the interface morphology.

The ab initio calculations have allowed us to investigate the question of the interaction with the substrate. The calculations show how a buffer plane of silicon carbides forms at the interface indicated by the arrow in Fig. 3(b), and that this decouples the plane of graphene from the substrate. The calculations also indicated that the plane of graphene is bonded by charge transfer from the substrate, which explains the strongest of the plane closest to the substrate. This explains why, even when several graphene planes are present, the main contribution of electronic transport is made by a single plane, as suggested by magneto-transport measurements.

Figure 3 (a) STM image of an inclined view of a single plane of graphene on a silicon carbide substrate face SiC(0001). The dark area in the image corresponds to the center of the hexagon, making up the honeycomb structure of graphene. The distance between the dots corresponds to the graphite lattice parameter. (b) Calculated density contours of this system (vertical section). The carbon buffer plane marked by the arrow is strongly coupled to the substrate by covalent Si–Si bonds, whereas the surface graphene plane is essentially uncoupled.

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Further Reading;
The growth of semiconductor nanowires is rapidly developing with potential for creating novel opto-electronic devices. We are interested in the nanowire geometry for two principal reasons: (i) Nanowires provide a new way to construct quantum dots, namely, to place a single quantum dot within a wire with controlled shape and density. They offer a new approach to the usual techniques of self-organized epilayer growth for quantum dots. (ii) Nanowires can provide optoelectronic devices with a wave-guiding of photons mediated by an inserted quantum dot. This can provide a single-emitter in a cavity through the operation of a single-photon generator and essential components for quantum cryptography and quantum computation.

We have developed growth techniques for such structures using the Large bandgap semiconductor systems GaN/AlN and CdSe/ZnSe, where the GaSe has a high percentage of single photons source can be made to operate at room temperature. The wires are grown by Molecular Beam Epitaxy directly on the substrates of the nitride materials. (Fig. 1) by using gallium catalyst layers to initiate 1-Dimensional growth of the selenium for GaN. Controlled columnar growth can be induced by an appropriate choice of the reaction between gallium and nitrogen fluxes. In contrast to the relaxed 2-Dimensional layers of GaN grown on mismatched substrates, GaN nanowires are essentially isolated objects, relaxed in a single layer with respect to the substrate and free of structural defects. Also, we can achieve one to several insertion of GaN between ALN barriers by switching the molecular fluxes (Fig. 1, right).

Wires of this kind can be isolated for measuring optical properties of an individual GaN emitter.

An optical study of the case of GaN nanowires containing CdSe/ZnSe dots is shown in Figs. 2. With this nanostucture, we have demonstrated controlled generation of single photons at 200K, at a temperature accessible with Peltier cooling devices. This is the highest operating temperature recorded for a semiconductor quantum dot.

This work was done by CNRS and ECA joint Grenoble group "Nanophysics of Semiconductor Devices".

Fig. 3: (a) Spectra of the emission from CdSe/ZnSe dots in GaN at 200K. (b) Histogram of the number of coincidence events for this wire at 200K. (c) Histogram of the number of time resolved photons detected after 5 detection events of a photon in a measurement event. (d) Zero order detection rate of a photon in a measurement event.

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Further Reading:
As physical objects become smaller, quantum effects become dominant and easier to measure. Thus, nanometer-sized quantum objects, in this work, serve as a propitious platform for observation of the new quantum phenomena associated with spin electronics. Such objects act as artificial atoms and can be controlled by external parameters such as magnetic field, electric field, potential, and light. With these electrons confined in the nanometer scale, quantum objects can be charged, and energy can be exchanged through Coulomb blockade and the Kondo effect. By using large gate parameters, they can also be controlled at cryogenic temperatures.

When the wave function that describes a large number of particles obeys the laws of quantum mechanics, it is often changed continuously, and the transition can be induced. In this ground state, with distinct symmetry, the liquid-gas transition of the quantum phase transition is fundamentally different from classical phase transitions. The Kondo effect, which is fundamental, plays a major role. By combining these quantum states with magnetic molecules, we can achieve this quantum phase transition by combining the quantum states of the magnetic molecule with the electronic states of the connection circuit.

We have shown that a single-molecule quantum dot can operate like a transistor at room temperature. The magnetic dot is placed in a magnetic field. The single-molecule quantum dot can be controlled by external parameters such as voltage applied to the gate, bias voltage, and grid voltage. By applying external voltages, the Kondo effect is suppressed, and a non-magnetic ground state is achieved. This allows us to observe the quantum phase transition in a single-molecule transistor.

Further reading:
Xavier Blase, CNRS silver medalist

CNRS researcher Xavier Blase, who arrived at the Néel Institute in March 2008, has been awarded the CNRS silver medal for "Major contributions to the development of ab initio quantum simulations in France."

Xavier Blase was recruited by the CNRS following his PhD with Steven Louie at the University of California-Berkeley, and post-doctoral work at the École Polytechnique in Fédérale de Lausanne. From 99 until 101, he was at the Laboratory of Condensed Matter and Nanostructures of the CNRS and the Lauder-Bernard Institute of Paris. His research work has explored a variety of fields in condensed matter physics, ranging from the growth mechanisms of nanotubes through superconductivity properties to diamond and doped silicon electronic transport in molecular systems. His methods development and applications have been invaluable to his theoretician colleagues, helping them to understand the extremely complex concepts and phenomena that any experimentalist he has worked with.

Over the years, Xavier Blase has been the basis of his subsequent career during his years at Berkeley and Lausanne. His numerical calculation work in solid state physics and especially the application of the development of the method of density functional theory (DFT) and on beyond the GGA approximation. Those years also coincided with an explosion in research in the nanosciences and other applications of the combination of theory and experiment, which has proved particularly important. This is essentially because the nanoworld is a place of very difficult tasks. From the small size of the objects, the spectrometers and microscopes need to be interpreted reliably, only with the help of ab initio calculations and simulations. In his respect, Blase’s skills in ab initio calculation techniques, together with his specialist knowledge of many aspects of solid state physics and nanostructures, brought him quickly to the forefront in this technical field, especially the well-known work of the intermediate models for carbon and boron nitride nanotubes.

Xavier Blase’s subsequent career has been characterized by his attention to the needs of experimentalists. His availability, his open-mindedness and his dynamism are such that the foremost researchers in material science have called on him, leading to numerous collaborations on both nanostructured materials, (nanotubes, nanowires,...) and on macroscopic materials, (clathrates, diamond and doped silicon...).

Xavier Blase has also convinced that scientific knowledge should be shared as widely as possible. He attaches considerable importance to communicating his results to non-scientists, and he has reflected extensively on the economic, social, and ethical consequences of scientific research. The CNRS’s decision to award him the silver medal is particularly gratifying and judicious a choice.

Text by Jean-Christophe Charlier
Professor at University of Louvain

The CNRS Silver Medal:

The CNRS awards limited number of Silver Medals each year to acknowledge and reward the most important scientific work in France. Xavier Blase’s distinction as a recipient of this prize follows the 2008 CNRS award of a silver medal to researchers in the CNRS Department "Mathematics, Physics, Planets and the Universe."
Revealing electronic crystals

At sufficiently low temperature, interacting electron-may crystallize and form a superstructure within their host atomic crystal. These ordering effects are at the core of the charge and orbital type instabilities in long wavelength modulation of the density and/or shape of the buttermost occupied electronic shells. The complex interplay between various interactions involving the great variety of different patterns such as checkerboards, ladders, strips, however, these are extremely difficult to observe experimentally because, typically, the ordering involves only a few electrons among thousands. Nevertheless, determining precisely which electronic or magnetic features are involved, and much less, their orientation and their electronic orbitals, however, has been made possible using x-ray diffraction techniques. In fact, the standard crystallographic methods are hard-pressed to reveal the positions of all the atoms involved in the electronic superstructure, and much less, their orientation in the electronic orbitals. However, the huge increase in sensitivity achieved in x-ray diffraction experiments has enabled the observation of so-called "resonance" x-ray diffraction, the energy of the incident photon is tuned to the energy of the photoelectric transition of one element, so that the photoelectron does not have the energy to escape the crystal but with a lower energy, the so-called "zero energy" valence electron diffraction, which allows the identification of the superstructure of the crystal, and the so-called "orbital ordering reflection".

We performed resonant x-ray diffraction at the O-K edge of a manganite and directly observed the superstructure within the electron orbitals. The O-K edge falls in the range of 50-100 keV, which requires a high energy x-ray beam. We used a synchrotron x-ray beam at the Swiss light source (Paul Scherrer Institute) and the soft X-ray undulator of the Laboratoire Henri Becquerel.

The x-ray diffraction intensity observed at the O-K edge provided evidence for ordering of orbitals within the oxygen atoms which is proportional to the density of the unoccupied states and to the Coulomb interaction strength.

Further Reading

NaI₃O₈ is a promising material for infrared nonlinear optics. The need for more intense infrared light to explore the coordination chemistry of metallic iodates led to the discovery of a new NaI₃O₈ phase. This compound is well-adapted for applications in the window of transparency of the atmosphere.

NaI₃O₈ crystallizes in the centric space group. The crystal structure contains the novel Ox³⁻ ion [O₅⁻]. The structure is characterized by the coordination of three iodate anions in a concentrated acid solution. It contains three polarizable lone electron pairs, which favour high nonlinear optical susceptibilities.

We have grown single crystals of NaI₃O₈ with millimeter sizes (Fig. 2). This is the key progress of our studies of the non-linear optical properties of crystals and for the development of device systems. Until now, only metallic iodate compounds, such as LiIO₃, have been available as the large single crystals required for full characterization of the non-linear properties.

Studies on powders have shown that NaI₃O₈ has a good thermal stability up to 50°C, high thresholds for optical damage (25 J/cm²) and high efficiency for second harmonic generation, which is comparable to that of LiIO₃. The spectrum of NaI₃O₈ shows a window of transparency from 5 μm to 2.5 μm (Fig. 3). Contrary to LiIO₃, which has a strong absorption band at 5.5 μm and two other bands around 1.5 μm and 2.5 μm, NaI₃O₈ is not hygroscopic and is transparent in the atmospheric window around 5 μm. Thanks to the additional metallic iodate ions, previously studied in halloysite in the halloysite family, the materials are chemically unstable. We believe that the iodate family could be an alternative to these materials.

In summary, the new compound NaI₃O₈ is a promising material for infrared nonlinear optics, and moreover, it opens an interesting path to new chemistry.

Further reading: