The pulsed field facility of KULeuven’s Institute for Nanoscale Physics and Chemistry

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Abstract. The pulsed field facility at the Katholieke Universiteit Leuven has recently been incorporated in the new Institute for Nanoscale Physics and Chemistry. The tradition of fruitful co-operation with other research groups has been further pursued. The laboratory has a magnet testing station and five user-friendly measuring stations that can be operated in parallel. Principal measuring techniques are magneto-transport, magnetization and photoluminescence; the research topics are high temperature superconductors, molecular magnets, diluted magnetic semiconductors, low dimensional metals, quantum dots and wires. The laboratory has established close co-operation with the LNCMP at Toulouse; in the context of large European facilities it has the status of a satellite user facility.

1. History of the facility
The facility was established by the late professor Van Itterbeek in the sixties [1]; it is the oldest surviving pulsed field laboratory in Europe. Since 1972, it was further developed to its present state by the first author and his collaborators. Highlights of the development have been given in a previous paper [2]. The 5 kV, 500 kJ capacitor bank that is now still in daily use was completed in 1988 at the occasion of the HFM-88 symposium [3]. This symposium was actually the link that established the series of RHMF conferences. The additional 10 kV, 500 kJ bank was completed a few years ago. The banks operate independently; the 5 kV bank is now fully computer-controlled and can serve four measuring stations simultaneously. In addition, there is a protected station for testing and breaking in new magnets.

In the tradition of accommodating and supporting guest researchers, the K.U.Leuven pulsed field facility has acquired the status of a satellite user facility of the LNCMP at Toulouse within the framework of the EUROMagNet Transnational Access programme [4], and as such has an active visitor programme. This was established in the context of the intensive and fruitful collaboration between the laboratories at Toulouse and Leuven in recent years.

In 2005, the pulsed field facility was incorporated in the new Institute for Nanoscale Physics and Chemistry (INPAC, directed by V.V. Moshchalkov), which is the centre of excellence at the K.U.Leuven for Nano-science and -technology [5]. INPAC is an interdisciplinary institute joining physics, chemistry, biology and technology. INPAC’s mission consists in the investigation of the effects of nanostructuring and nanoscale confinement of charges, spins, and photons on the electrical, magnetic, optical, and chemical properties of inorganic, organic and biomaterials in order to reveal the
The experimental facilities of INPAC are grouped together in six major divisions: i) **Thin film preparation** - Molecular beam epitaxy, Sputtering & Evaporation, Low energy ion deposition/implantation, Cluster beam deposition, Electro-chemical deposition, Spin casting, Potentio-control adsorption, Langmuir-Blodgett layer deposition, ii) **Nanostructuring techniques** - E-beam patterning, Ion beam patterning, STM-writing, Optical lithography, Nano-manipulation, Self-assembly, Self-organized etching, Melt quenching, (iii) **Local probe techniques** - Scanning tunnelling microscopy (low temperature and vacuum), Scanning tunnelling spectroscopy (low temperature and vacuum), Atomic force microscopy (low temperature, ambient, in fluids), Magnetic force microscopy (low temperature), Scanning probe microscopy in fluids, Scanning Hall probe microscopy, iv) **Measuring integrated physical properties** - Time resolved, laser induced opto-acoustic calorimetry, SQUID magnetometry, Vibrating sample magnetometry, High (pulsed) magnetic field resistivity and magnetization, Mössbauer spectroscopy, X-ray magnetic hyperfine spectroscopy, Neutron scattering, Center of mass...
spectroscopy (low temperature), Perturbed angular correlation spectroscopy, I-V, C-V, and s-V analysis, v) Measuring integrated structural properties - X-ray diffraction (XRD), Auger spectroscopy, X-ray photoelectron spectroscopy (XPS), Micro-Raman and resonant Raman spectroscopy, Rutherford backscattering spectrometry (RBS), Elastic recoil detection analysis (ERD), Ion beam channelling, Reflection high energy electron diffraction (RHEED), Scanning electron microscopy (SEM), Transmission electron microscopy (TEM), Electron spin resonance spectroscopy (ESR), Internal photoemission spectroscopy (IPE) and finally vi) Optical techniques - Ultraviolet-visible spectro-photometry (UV-VIS), Time resolved spectroscopy, Photo-ionisation spectroscopy, Mass spectroscopy, Quasi-elastic light scattering, Hyper-Rayleigh scattering, High (pulsed) magnetic field photoluminescence, Confocal microscopy, Magneto-optical Kerr effect, Transient photoconductivity, Fluorescence assisted cell sorter. The theoretical modelling tools available in INPAC are Time dependent Ginzburg-Landau, Bogoliubov-de Gennes, Ab-initio calculations, Abrikosov-Gor'kov, Kohn-Sham density functional theorem, Car-Parrinello density functional theorem, Molecular dynamics simulations and Monte-Carlo simulations.

3. Nano-science and -technology: the need for high pulsed magnetic fields

There are basically three fundamental reasons why high magnetic fields are essential for the study of solid state systems: i) to induce and tune confinement in real (r) and reciprocal (k) space, ii) to lift degeneracy of quantum states and to select quantum states (e.g. effective mass, g-factor, symmetry breaking effects) and iii) to break up correlations between carriers (superconductivity and magnetism). For the link with nano-science and -technology, the most important topic is (i). In individual nanostructures, the behaviour of Landau levels in high magnetic fields reflects a fundamental crossover from the weak field regime, where the magnetic length \( l_c = \sqrt{\frac{\hbar}{eB}} \) is larger than the size of the structure, to the high field limit, where the magnetic length is smaller than the size. For a lateral size of about 5 nm the crossover field is \( \approx 26 \text{ T} \); this motivates the use of high magnetic fields. As an example, for superconducting nanostructures the lowest Landau level, obtained with appropriate (superconducting) boundary conditions, is nothing else than the nucleation line \( T_c(H) \).
hundred tesla are needed since the superconducting critical temperatures $T_c$ are in the range of 10 K to 100 K (see figure 2, right frame) [7].

For low dimensional semiconductor systems in high fields, the Landau level filling factor can become close to one; this allows these systems to be studied close to the quantum limit. Ideal semiconductor structures are quantum dots and quantum wires. Besides the interest for optical communication technology, several fundamental physical properties (effective masses, exciton radii, etc.) can be determined using photoluminescence experiments in high fields (see figure 2, left frame) [6].

4. Magnet Technology
The K.U.Leuven pulsed field group has made major contributions to magnet technology. One of these is the switching of capacitor banks with power thyristors in the surge mode [8] that is now used at most pulsed magnet laboratories. In coil design, the system of optimised internal reinforcement with fibre composites was invented and consistently further developed [9]. Because of its efficiency and ease of construction, this coil design has now been adopted by most pulsed field laboratories. For the optimisation, user-friendly computer codes “PMDS” have been developed for efficient use on a personal computer [10]. A recent development still under way is the multi-composite wire, a new type of wire that can be tailored to desired performance, and that is easier to wind than a strong wire with microfilaments or a steel mantle [11]. Nowadays it is possible to buy pulsed magnet coils, for example from our spin-off company Metis [12], but the design of new types of high performance magnets is a challenge that can only be met by the dedicated laboratories.

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