The Humboldt High Magnetic Field Center at Berlin

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Abstract. The Humboldt High Magnetic Field Center is operated by the Chair for Magnetotransport in Solids of the Department of Physics of the Humboldt-Universität zu Berlin. It provides DC-magnetic fields up to 20 T, pulsed nondestructive fields of up to 60 T and megagauss fields of up to 331 T using a single-turn coil generator for experimental application focusing on solid state physics. Magneto-optical investigations are carried out in the MIR, NIR and visible wavelength range as well as transport and magnetization experiments.

The facility is open to the scientific community and welcomes users within the European project EuroMagNET. The laboratory will be closed in fall 2006 but its experimental facilities will be further accessible to the community in other labs. The single-turn coil generator will be transferred to LNCMP, Toulouse, France, continuing to provide applicable megagauss fields to the European Community.

1. Introduction
The Humboldt High Magnetic Field Center (HHMFC) is operated by the Chair for Magnetotransport in Solids of the Humboldt-University at Berlin (HUB). The HHMFC is dedicated to solid state science using high magnetic fields. The fields in the HHMFC can be generated with DC magnets, nondestructive pulsed magnets and semidestructive single turn coils (STC). The resulting fields available are up to 20 T, 60 T and larger than 300 T, respectively.

2. Non-destructive Magnets
The HHMFC operates two DC magnets, a 15 T and a 20T superconducting solenoids. These magnets are used for transport measurements, magnetization and magneto-optical experiments. The temperature can be varied from 0.3K to 300K.

A nondestructive pulsed magnet has become operational again. It features a maximum field of 62 T in a 17.5 mm bore with 10 ms pulse length using a 10 kV/400 kJ capacitor bank discharge. In these coils the copper windings are reinforced by glass-fibre/epoxy. Magneto-optical, transport, magnetization, as well as magnetoluminescence experiments can be performed with this magnet between 0.3 K and 77 K.

3. Single Turn Coils
Magnetic fields of up to 331 T can be generated semidestructively using the single turn coil technique [1]. To obtain these fields a discharge of a capacitor bank of 60 kV/200 kJ into a small disposable lightweight copper coil is used. The coil is oriented vertically enabling the use
Figure 1. Left: Field pulses for various coil diameters at 55 kV discharges. Right: Peak magnetic field vs. charging voltage obtained for different coil diameters. The coils have been made from copper sheets of 3 and 2.5mm thickness, respectively.

of common bath cryostats. Typical fields of 140 T can be generated in a 15 mm bore using 50 kV discharges. The maximum field available for experimental use is 311 T in a 5 mm bore at 60 kV, the absolute maximum field magnitude achieved so far is 331 T in a 3 mm bore at 55 kV. At 60 kV no further rise in field magnitude was obtained as the transfer of energy into a rapidly expanding and heated conductor provides a limit as was previously reported by other groups [2]. We present this maximal field to provide comparison with the respective parameters reported from other laboratories [2, 3, 4]. The peak field is strongly dependent on charging voltage and therefore on energy as well as on coil diameter as shown in Figure 1. The characteristic pulse rise time is of order 1.0-2.5 $\mu$s and 6 $\mu$s for total pulse length. The rise time is shorter the smaller the coil diameter, hence its inductance, is.

4. Experimental support
The HHMFC employs a wide range of sophisticated experimental setups used for a great variety of experiments in solid state physics. The highlights are transmission/reflectivity measurements with monochromatic radiation of wavelengths suited for the given magnetic field magnitudes. Transport, magnetization, luminescence and absorption measurements are also routinely performed. We cover the cm to ultraviolet wavelength by using carcinotrons, optically pumped lasers, IR- and HeNe Laser, Ar-, dye and Ti-Sapphire Lasers. For the nondestructively generated fields with pulse lengths longer than few ms, elaborate detector- and data recording-systems including OMA enable also the application of high-frequency digital lock-in techniques [5, 6].

STC-Magnetization measurements are performed using the compensated-pick-up-coil technique. Currently we are able to perform magnetization experiments in fields up to 180 T at temperatures of as low as 4 K, up to 150 T at 1.6 K. Cyclotron resonance experiments can be performed semi-destructively at temperatures between 6 and 300 K up to 150 T and up to 300 T at nitrogen temperatures. Moreover, we have set up techniques for measuring reflectivity
Various other spectroscopic techniques are continuously being added to our experimental portfolio with a prime focus on Voigt, Faraday and reflectivity geometries using optical fibers for wavelengths in the visible light, near infrared and mid infrared.

The installation of a high frequency-proof Faraday-cage resulted in a signal to noise ratio that is limited by the SNR of the detection equipment but not by the electromagnetic noise generated during the capacitor discharge of the STC.

The further development of nondestructive ways of operating the STC using an elaborate steel reinforcement enables us to produce oscillating fields of up to 65 T with very small damping constant. We have analyzed our previous setup [7] to abolish losses due to dissipation of energy into the steel reinforcement. The nondestructive operation now gives a field of \( \approx 10\% \) less than the free coil at a given voltage compared to more than a third less before. An example field for both, reinforced and semi-destructive operation of the STC is given in fig. 2.

That means, additional to the very convenient property of STC fields to have an up and down sweep that enables us to check the authenticity of the recorded signals and detect dynamic processes, we can use the oscillating field to change field polarity and sweep direction up to 8 times on a microsecond timescale within one pulse proving further insight to physical processes.

We can use this extremely fast and recurring field inversion to study low field magnetization and other effects. Moreover, we are able to directly compare experimental results obtained in magnets with equivalent magnetic field magnitudes but field derivatives of order \( 10^{-2} T/s \) via \( \approx 10^{3} T/s \) to up to \( \approx 10^{7} T/s \).

5. Current Activities
A major focus of the work in the HHMFC is currently the comparison of data obtained in magnets providing similar magnitudes but sweep rates that are several orders of magnitude...
different. To be able to do so we developed techniques from STCs for DC magnets and vice versa. A remarkable extension is eddy current spectroscopy [8] with which we are able to contactlessly determine semiconductor conductivities in megagauss fields.

To achieve this we can use the standard magnetization equipment in STCs and a careful analysis of the magnetic diffusion process in a semiconducting rod that is placed in the compensation coils. A further description is given in [9].

6. Future prospects
The HUB has decided not to continue operating the HHMFC beyond the retirement of one of the authors (M.vO) in autumn 2006. However, the sophisticated magnets and additional equipment will be preserved for future application in the EuroMagNET framework. The most noteworthy process will be the transfer of the single turn coil generator to the Laboratoire National de Champs Magnétiques Pulsés in Toulouse. This will provide the extension of available magnetic fields in Toulouse to above 100T and the free access for the scientific community to a 100 T and above user magnet within Europe.

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