Sci. Rep. RITU A42 (1996) pp. 255-257
No. 2, May 1996

# The Project for the New High Field Facility*

M. Motokawa

*Institute for Materials Research, Tohoku University, Sendai 980-77, Japan*

(Received February 16, 1996)

Since High Field Laboratory for Superconducting Materials attached to Institute for Materials Research of Tohoku University started, 15 years has passed. We have had plenty of fruitful scientific and technological results not only in a field of superconductivity but also in areas of magnetism, semiconductors, organic conductors, chemical and biological materials and crystallography. The equipments in the Laboratory, however, are now getting aged and the available high field of 31 T obtained by our hybrid magnet, which used to be the highest in the world, must be graded up. The committee of the Laboratory has been discussing on the development of equipments and expansion of research fields for the new facility.

KEYWORDS: project, hybrid magnet

## 1. Introduction

The history of high field research in IMR is long. In 1935~1939, our Institute introduced a Kapitza type pulsed high field magnet and application of high field to research on magnetic materials started. It was only 3 years later since Kapitza produced 30 T for the first time in the world at Cavendish Laboratory of Cambridge University. Unfortunately, however, the high field magnet was destroyed during the war and the details of the obtained scientific results have been lost. It should be emphasized that the Institute has installed the highest level equipment in the world at that time and recognized the importance of high field experiments for material science. This fact has caused later an activity of high field science in Japan.

In 1955, our country was still unstable and poor due to the aftereffect of the war, but our Institute installed a Bitter type water-cooled magnet first in Japan. It produced steady fields up to 12.5 T and actively used for researches of magnetic materials, semiconductors and so on mainly by Fukuroi, Hirone and Kanda groups. Discovery of two-step metamagnetic transition of $CoCl_2{\cdot}2H_2O$ was one of the most well-known researches at that time[1]. This material have been investigated in the whole world after this discovery and led to progress of researches on low-dimensional magnetism. New concept of "Spin-Cluster" in Ising spin system, for instance, was first introduced by Date in this material[2]. This high field facility played an important role in developing new materials and new concepts during 1955 to 1970.

A hybrid magnet was developed in Francis Bitter National Magnet Laboratory at MIT and became used up to 30 T in the 1970's. They were also installed at Nijmegen in The Netherlands in 1976 and Grenoble in France in 1982. As the third generation of a high field magnet in our Institute, it was planned to install a hybrid magnet in 1979 and a new facility called "High Field Laboratory for Superconducting Materials" started in 1981. The purpose of this facility at the first step was to develop superconducting materials to be used for a nuclear fusion furnace. The collaborations with groups in other Universities, National Research Laboratories and Companies have been intensively made. By using the Ti added $Nb_3Sn$ explored in our Laboratory, it was succeeded in producing 31.1 T which was the highest record in the world in 1986[3]. Up to 1991, this facility has contributed to developments of high $T_c$ superconductors, for example, increase of the critical current in high magnetic fields, and led to possibility of using them at liquid nitrogen temperature. The Laboratory had its 10th anniversary in 1991 and since then remarkable developments have been made on highly strengthened superconducting wires[4] and on so-called helium-free superconducting magnets[5]. The highly strengthened superconducting wire will reduce the weight of superconducting magnets up to 1/3 of present ones, which means it will save space and consumption of liquid helium. The helium-free superconducting magnets will contribute to the long time use of high field without liquid helium consumption. These are revolutionary inventions and are

---

*IMR, Report No. 2031

strongly related to our project.

On the other hand, in addition to research of superconducting materials, our Laboratory has been used for other areas of science since approximately 1985, when the first step of superconducting materials research was performed. The main results are as follows: Magnetization measurements of many kinds of magnetic materials, especially $R_2Fe_{14}B$ (R=rare earth elements)[6] related to the novel permanent magnet $Nd_2Fe_{14}B$, observation of magnetic quantum oscillation of organic superconductors like $(BEDT\text{-}TTF)_2X$[7], observation of 1/7 fractional Hall effect of two-dimensional electron system at the interface of GaAs/AlGaAs hetero-junction[8], measurements of field dependence of magneto-optical effects of semiconductors[9], magneto-photoluminescence of semimagnetic semiconductors in high pressures up to 15 GPa[10], high field effects on crystal growth [11], chemical reactions[12] and biological phenomena[13]. These research areas are now still expanding and also related to our project.

## 2. Present status and trend of high field facilities

It seems that the high magnetic field science is coming to the turning point. The steady field above 40 T is now considered to be possible due to the technical and material developments and the some facilities in the world are planning to build a 40 T magnet. In the United States, Francis Bitter National Magnet Laboratory, was historically important, and now a new facility is founded at Florida State University. It has 24 MW electric power supply and produces fields as high as 32 T by only a water-cooled magnet. The poly Bitter type magnet is composed of disks of Cu-Ag alloy, which was developed in our country. A hybrid magnet is planned to generate fields higher than 45 T in near future[14]. High Magnetic Field Laboratory in Grenoble, France, is planning an upgrade of the hybrid magnet up to 40 T using 20 MW power supply. National Research Institute for Metals in Tsukuba, Japan, has succeeded in generating 36 T by a hybrid magnet installed recently with 15 MW power supply.

The research areas are also expanding more quickly and more widely. The applications are not only to superconductivity and magnetism, but also to other wide regions of material science. We can expect strong effects even on diamagnetic materials. For example, even water has a strong repulsive force and most of polymers show polarization effect in such a high magnetic field. These effects may contribute to unknown phenomena in chemical and biological reactions. The field effect is considered to be as high as about 2 times in such systems when the field is increased from 30 to 40 T, because it is proportional to the square of the field intensity.

Our Laboratory is also facing the time to renew the hard wares and to expand the research fields as well as other high field facilities. 40 T hybrid magnets planned in other facilities are supposed to consume a huge amount of electricity. In our Institute, however, it is almost impossible to use electric power larger than 10 MW because the cost of electricity is about 10 times more expensive than in The United States. So we are considering to build a compact 40 T hybrid magnet. The important points of the design for this magnet are to use the highly strengthened superconducting wire developed in our Laboratory for the outer superconducting magnet part and Cu-Ag alloy poly Bitter type coil for the inner water-cooled magnet part. This magnet must be combined with very stable power supply for the precise measurements. To take an advantage of steady field, the ultra low temperature system will be important. The steady field is superior to the pulsed field in order to obtain ultra low temperature using the dilution refrigerator system. The high pressure equipment will be also available. In addition to a hybrid magnet, some helium-free magnets which produce up to 10 T with a large bore must be installed. This type of magnet has a possibility to be used as the outer part of hybrid magnet in future. Details of these magnets are described in the section of Magnet Technology in this issue.

## 3. What kinds of researches can be planned by these magnets?

In superconducting material research, high fields have been being used so far mainly for characterization of the developed wires. High fields, however, will be used more actively for fundamental research of superconductivity. We have to develop new subjects of science connected to condensed matter physics, chemistry, biology and material processing technology. Synthesizing many kinds of materials in high magnetic fields will be a new subject. High fields is supposed to be useful for fundamental physics to create a new concept. Discovery of novel unknown phenomenon may be expected in such an extreme condition.

The following ideas are not necessarily new but some are those which could not be performed before due to the technical difficulty but now possible.

(1) Development of superconducting materials

The main purpose is to make a superconducting magnet employing the high $T_c$ superconductors, which will enable us to produce steady fields higher than 50 T. If it would be realized, we will not need huge electric power for high field science. Needless to say there are many applications.

(2) Development of highly functional materials

Chemical reactions and synthesis in high magnetic fields are strongly related to the new technique to control atoms and molecules and they will contribute to new processes of synthesizing organic and inorganic materials. The interesting point is that we may have possibilities to produce novel highly functional materials in high magnetic fields. For these purposes, we need magnets which can be used continuously long time. Superconducting magnets which have been used so far, however, require plenty of liquid helium and electricity and difficult to be used continuously long time from the economical point of view. The helium-free magnet developed in our Laboratory is very useful for these purposes and this research field is expected to expand quickly and widely.

(3) Research on electronic systems in solids

Quantum effects in high magnetic fields on mesoscopic materials like low-dimensional organic conductors, quantum dots, quantum wires, super lattices are interesting. Electronic states of amorphous, highly correlated electron systems, flux state of high $T_c$ superconductors are also important. Detailed investigation of these systems will cause discovery of new phenomena or open new research fields.

(4) Research on magnetic materials

High field research on magnetic materials related to heavy Fermion systems or Kondo effect are still interesting and uranium compounds seems to be important for both fundamental physics and future application. Investigations of magnetic properties of multi layer system of magnetic metals and granular materials in high fields are also important. Development of permanent magnets with large energy product is involved in this category. Synthesis of magnetic thin films or magnetic compounds in high fields will give us some interesting results.

(5) Field effect on crystal growth, chemical and biological reactions

Even diamagnetic materials have strong effects induced by high fields. Field effects on organic compounds, biological materials, gene, photosynthesis of plant etc. Blood will be polarized in high field as well as polymers and its influence to life is still unknown. These researches are important because recently people has more opportunity to be in magnetic field for medical treatment.

As mentioned above, some projects are briefly described, and new and more interesting ideas on the way of researches in high magnetic fields are expected.

1) T.Haseta and H.Kobayashi, J.Phys.Soc.Jpn. **19** (1964) 765.
2) M.Date and M.Motokawa, Phys.Rev.Lett. **16** (1966) 1111.
3) Y. Muto, Y. Nakagawa, K. Noto, S. Miura, A. Hoshi, K. Watanabe, G. Kido, H. Ichikawa, T. Fujioka, Y. Sato, O. Osaki and H. Takano, Sci. Rep. RITU **33** (1986) 221.
4) K.Watanabe, A. Hoshi, S. Awaji, K. Katagiri, K. Noto, K. Goto, T. Saito and O. Kohno, IEEE Trans. Appl. Supercond. **3** (1993) 1006.
5) K.Watamabe, Y. Yamada, J. Sakuraba, F. Hata, C. K. Chong, T. Hasebe and M. Ishihara, Jpn. J. Appl. Phys. **32** (1993) L488.
6) H. Kato, M. Yamada, D. W. Lim, T. Iriyama, G. Kido and Y. Nakagawa, Sci. Rep. RITU **38** (1993) 161.
7) T. Sasaki and N. Toyota: Sci. Rep. RITU **38** (1993) 353.
8) S. Kawaji, J. Wakabayashi, T. Okamoto, A. Fukano, K. Hirakawa, M. Nagata, K. Hirakawa, H. Sakaki, Y. Koike, T. Goto and T. Fukase, Sci. Rep. RITU **38** (1993) 289.
9) I. Mogi, N. Adachi, T. Kokubun, M. Inoue, G. Kido, J. R. Anderson and Y. Nakagawa, Sci. Rep. RITU **38** (1993) 261.
10) N. Kuroda and Y. Matsuda, Sci. Rep. RITU (this issue).
11) Y. Aoki, G. Kido and R. Ninomiya, Sci. Rep. RITU **38** (1993) 373.
12) S. Okubo, I. Mogi and Y. Nakagawa, Sci. Rep. RITU **38** (1993) 383.
13) O. Okai, N. Okamura, I. Mogi and G. Kido, Sci. Rep. RITU **38** (1993) 406.
14) J.E.Crow, L.Campbell, D.M.Parkin, H.J.Schneider-Muntau and N.Sullivan, Physica B **211** (1995) 30.