Fizika Nizkikh Temperatur, 2000, т. 26, No 11, p. 1166–1169

Chronicle

NATO advanced study institute «Modern Trends in Magnetostriction Study and Application»

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Received June 27, 2000

The NATO advanced study institute «Modern Trends in Magnetostriction Study and Application» was held from May 22 to June 2, 2000 in Kyiv, Ukraine. The co-directors and main organizers were V. G. Bar'yakhtar (Ukraine), V. V. Eremenko (Ukraine), M. R. J. Gibbs (UK), H. Szymczak (Poland), and V. A. Sirenko (Ukraine). The computer services were provided by L. D. Demchenko, N. I. Makedonskaya, and Yu. A. Shabakayeva (Ukraine); local administrators L. A. Chekal and T. N. Loshitskaya (Ukraine).

The objectives of the ASI were to determine the state of the art of the basic and applied research of magnetostriction and related phenomena; to define and prioritise directions of investigation in the future; to consider new materials for common applications of magnetostriction-based devices; to formulate new perspectives on magnetostriction phenomena and applications, using advances in materials design and technology. The specific topics included general introduction to modern trends in magnetostriction study and application; theory of magnetostriction and related phenomena; rare earth magnetostriction study and application; magnetostriction of amorphous materials; CMR materials; giant magnetostriction in superconductors; structural study of magnetostriction; industrial applications and magnetostriction of nanostructured materials.

The phenomenon of magnetostriction was discovered more than 150 years ago (Joule J. P., *Phil. Mag.* **30**, 76 (1847)). Since that time there has been both study of the basic science and application in such areas as the generators of sound, magnetoacoustic transformers, actuators for opto-electronic systems, devices for non-destructive control and remote detection and ranging. The recent development of modern technologies, such as microfabrication, and materials, such as rare earth-based bulk materials and magnetic thin films, has produced new opportunities for the study and application of magnetostriction. Thus, discovery of *giant magnetostriction* enables one, in particular, to generate ultrasound and extend the usage of the non-destructive control techniques; development of cryogenic technologies gives new insight into forced magnetostriction, namely to its irreversible component, related to *magnetization reversal and thermoactivated processes*, which are involved in displacement *of the domain walls and flux lines*, i. e., stability of magnetic and superconducting devices, as well as to the giant magnetostriction in *rare-earth magnets* (up to 10^{-2}). The new field of the interest in magnetostriction as the strain derivative of *magnetic anisotropy* is relevant to *magnetic recording industry*, particularly as recorded densities go beyond 20 Gbits/in^2. As physical dimensions of devices are reduced, the surface area to volume ratio

increases and surface anisotropy (magnetostriction) effects may become significant in terms of ultimate switching speeds or noise floor. Miniaturization within the sensor/actuator sector also may invoke such complications, and also now make magnetostrictive materials competitive with piezoelectric materials. There has been a resurgence of interest in perovskite materials, particularly for their outstanding magnetoresistive properties. The fundamental mechanisms driving the observed effects are still being elucidated, but lattice distortion (Jahn–Teller) and significant magnetostrictions appear to play a part. There is an urgent need for coherent studies in this area.

Magnetic field induced giant magnetostriction has recently been discovered in high-temperature superconductors. The magnetoelastic strains may limit technical applications of this important group of materials.

Spread of the novel experimental techniques like *magnetic resonances, neutron scattering, modern x-ray facilities* to magnetostriction examination, allows high resolution *structural studies* of magnetostriction and the differentiation of its surface and bulk components. It is timely to review and explore the various possibilities offered here, and attempt to co-ordinate the use of large scale facilities to maximize the scientific output.

The goals of the proposed ASI were delivery of lectures on new achievements and discussion of the listed potentials for the study and application of magnetostriction study among experts from the different branches of science and industry, presenting the leading teams of the West and Eastern Europe. It is hoped that a more co-ordinated and focussed approach at both the level of fundamental science and demonstrator applications, moved the subject on significantly. Wide dissemination of the meeting via publications will be an important outcome. The recent opening up of Eastern Europe makes such a meeting practical, as before much expertise lay beyond the reach of western scientists. This ASI was the first forum on modern trends in magnetostriction study and application. Only a meeting of this kind, supported by NATO, allowed us to gather the worldwide acknowledged specialists in the related fields, capable to promote the solution of the existing problems and identify the future prospects. To participate in ASI near 70 experts have arrived from 14 European countries and USA. 16 lectures was delivered by world-known experts on magnetostriction:

* J. I. Arnaudas (Universidad de Zaragoza, Spain) «Magnetostriction of rare-earth based thin films and superlattices»;
* V. G. Bar'yakhtar (Institute of Magnetism, Ukraine) «Magneto-acoustic resonance»;
* J. M. Barandiaran (Departamento de Electricidad y Electronica; Universidad del Pais Vasco (UPV/EHU), Spain) «Magnetoelasticity in amorphous ferromagnets»;
* H. Chiriac (National Institute of R&D for Technical Physics, Romania) «Giant magneto-impedance effect in amorphous wires»;
* B. Dabrowski, Z. Bukowski, S. Kolesnik, O. Chmaissem, J. Mais, and C. W. Kimball (Department of Physics, Northern Illinois University, USA) L. Gladczuk, A. Wisniewski, A. Szewczyk, M. Gutowska, and H. Szymczak (Institute of Physics; Polish Acad. of Science, Poland) «Spectacular magneto-related properties of complex oxides»;
* V. V. Eremenko and V. A. Sirenko (Institute for Low Temperature Physics & Eng., Ukraine) «Magnetostriction and spin-flopping of uniaxially compressed antiferromagnets. Comparison with superconductors»;
* A. Gerber (Tel-Aviv University; School of Physics and Astronomy, Israel) «Magnetostriction in superconductors»;
* M. R. Gibbs (The University of Sheffield; Department of Physics & Astronomy, UK) «Magnetostriction of multilayer systems»;
* M. Hirscher (Max-Planck-Institut fur Metallforschung, Germany) T. Reininger (Festo AC & Co., Germany) «Fundamental investigation and industrial applications of magnetostriction»;
* M. R. Ibarra, J. M. De Teresa, P. A. Algarabel, C. Marquina, and B. Garcia-Landa (Dpto. Fisica de la Materia Condensada and ICMA, University of Zaragoza-CSIC, Spain) «Magnetostriction in colossal magnetoresistance manganese oxide perovskites»;
* A. Ludwig and E. Quandt (Caesar, center of advanced studies and research, Germany) «Rare earth transition metal thin films and devices»;
* R. F. Pettifer (University of Warwick; Department of Physics, UK) «Structural study of magnetostriction»;
* K. V. Rao (Dept. of Material Science-Tmfy-MSE; Royal Institute of Technology, Sweden) «Local Magnetostriction Determination and Mapping Using Atomic Force Microscopy»;
* H. Szymczak (Institute of Physics, Polish Academy of Science, Poland) «Magnetostriction in heterogeneous magnetic systems»;
* Ruqian Wu (Department of Physics and Astronomy, California State University, USA) «First

principles determination of magnetostriction in surfaces, bulks, alloys and compounds»;

The posters and progress reports were presented:

* A. I. Abramovich (Moscow State University; Physics Department, Russia) «Giant volume magnetostriction in GMR manganites $Re_{1-x}Sr'_x MnO_3$ (Re = Sm, Nd)»;

* G. E. Grechnev and A. Baranovskiy (Institute for Low Temperature Physics & Eng., Ukraine) «Origin of magnetovolume effect in $GdAl_2$ and $GdNi_2$ compounds»;

* A. B. Beznosov, E. L. Fertman, and V. V. Eremenko (Institute for Low Temperature Physics & Eng., Ukraine) «Electronic structure & magnetostrictive sensitivity of metallic glasses Fe–B»;

* C. Canalias, J. Wittborn, Ni. Polushkin, and K. V. Rao (Royal Institute of Technology; Engineering Materials Physics, Sweden) «Magnetic studies of nanoscale laser patterned structures»;

* Chernyavsky Oleksandr (Charles University; Dep. of Electron Structures, Czech Republic) «Field induced irreversibilities in an itinerant 5*f* electron UNiAl antiferromagnet»;

* Fergen Immanuel (Forschungszentrum Karlsruhe; Inst. for Materials Research I, Germany) «The influence of stress induced anisotropy on the hf-properties of amorphous films»;

* Franco Victorino (Sevilla University;Fisica de la Materia Condensada, Spain) «Magnetic anisotropy and devitrification of soft magnetic materials»;

* V. I. Gatalskaya, S. Barilo, G. L. Bychkov, and L. A. Kurochkin (Inst. of Solid State & Semiconductors; Physics NAS RB, Belarus), H. Szymczak, R. Szymczak, and M. Baran (Institute of Physics, Polish Academy of Science, Poland) «Magnetic properties of $La_{1-x}Li_xMnO_3$ single crystals»;

* L. I. Koroleva (Moscow State University; Physics Department, Russia) «Peculiarities of volume magnetostriction in $La_{1-x}Sr_xMnO_3$ at Curie point region»;

* Kraus Ludek (Institute of Physics ASCR, Czech Republic) «Stress dependence of giant magnetoimpedance and its potential applications»;

* K. V. Lamonova and A. L. Sukstanskii (DonFTI, Ukraine) «Magnetoelastic interaction and a new type of domain walls in a magnetic sandwich structure»;

* Lupu Nicoleta (National Inst. of R&D for Technical Phys.; Magnetic Materials & Devices, Romania) «Melt spun amorphous magnetostrictive bimetal ribbons»;

* Minguez Pablo (University of the Basque Country, Spain) «Magnetoelastic properties of $Fe_{73.5-x}Al_xSi_{13.5}B_9Cu_1Mo_3$ alloys ($x = 0, 2, 4, 6$)»;

* W. R. McCallum (Iowa State University; Center for Rare Earths & Magnetic, USA) «Composite magnetostrictive material for sensors and actuators»;

* S. Nikitin (Moscow State University; Physics Department; Russia) «Magnetostriction, magnetocaloric and magnetoelastic effects in rare-earth compounds»;

* Yu. G. Pashkevich, V. A. Blinkin, V. P. Gnezdilov, V. S. Kurnosov, V. V. Tsapenko, V. V. Eremenko, P. Lemmens, M. Fischer, M. Grove, G. Gentherodt, L. Degiorgi, P. Wachter, J. M. Tranquada, and D. J. Butrey (DonFTI, Ukraine) «Optical studies of the interaction of charge, magnetic & lattice subsystem in stripe ordered phase of $La_{1.775}Sr_{0.225}NiO_4$»;

* Oleksandr Prokhnenko (Institute of Physics ASCR; Czech Republic) «Magnetovolume Anomalies in $Ce_2Fe_{17-x}Mn_x$ compounds»;

* Sasso Carlo Paolo (IEN, G. Ferraris; Material Department, Italy) «Analysis and optimization of the magnetomechanical properties of terfenol-D composites at audio frequencies»;

* Yu. Shabakayeva, V. V. Eremenko, V. A. Sirenko, N. I. Makedonskaya, V. Bruk, and M. Shvedun (Institute for Low Temperature Physics & Eng., Ukraine), H. Szymczak (Institute of Physics, Polish Academy of Science, Poland) «About irreversible magnetostriction in perovskite-like structures»;

* I. V. Svechkarev, A. S. Panfilov, M. Kurisu, A. Fuse, and G. Nakamoto (Institute for Low Temperature Physics & Eng., Ukraine) «Effect of pressure on magnetic susceptibility of $CeCo_2$»;

* Irina Tereshina (Moscow State University; Physics Department, Russia) «The effect of hydrogen on magnetostriction of rare-earth compounds $R_{1-x}R'_x Fe_2$»;

* I. O. Troyanchuk, K. Baerner, and S. Trukhanov (Inst. of Solid State & Semiconductors; Physics NAS RB, Belarus), H. Szymczak (Institute of Physics, Polish Academy of Science, Poland) «Effect of oxygen content on magnetic and magnetotransport properties of the manganites»;

* S. A. Volokhov, P. N. Dobrodeev, A. V. Kildishev, and J. A. Nyenhuis (Institute of Electrodynamics NASU; Department of magnetism, Ukraine) «Magnetic methods of monitoring microstructural changes in ferromagnetic pipelines»;

* J. Wittborn, F. Bros, K. V. Rao, J. Noques, A. Hottman, and Wan H. Sehuller (Royal Institute of Technology; Engineering Materials Physics, Sweden) «Local magnetostrictive response using atomic force microscopy measurement and domain

imaging of nanoscale magnetic dots on Si substrate»;

* A. A. Zvyagin, G. A. Zvyagina, and D. M. Apalkov (Institute for Low Temperature Physics & Eng., Ukraine) «Magnetic anisotropy of quantum low-dimensional magnets induced by the elastic subsystem of crystal».

From the discussions on various classes of materials a number of themes emerged. Amorphous ferromagnets (ribbons, wires or films) are quite well understood, and the reviews presented here demonstrate a mature subject. Thin film and multilayer materials present a number of challenges, and experimental and theoretical effort must still be expended to move the subject from a phenomenological to more mechanistic and predictive view of the effects of surfaces and interfaces. Work on manganites and superconductors can clearly benefit from magnetostriction studies, as the transport and magnetic properties are so intimately connected to lattice properties (Jahn-Teller distortions, polarons etc). The complimentarity of magnetostriction studies to more traditional magnetization measurements was clearly brought out. Measurement of magnetostriction remains somewhat contentious. There remains a paucity of data on systems as common as NiFe where temperature and stress effects are almost unknown. It was exciting to see the possibilities which may come from the use of advanced light sources (ESRF) and diffraction studies, but other methods need further analysis of accuracy and precision. It may be appropriate to organize a round-robin experiment. Applications of magnetostriction to sensing and actuation span the very large (active vibration control) to the very small (MEMS). Note was made of cost and the conservatism of industry to move to new materials and technologies, but the emphasis was again made that the remote action possible through inductive drive or sensing can offer significant advantages, and the large figures of merit predicted for magnetoelastic sensors compared with semiconducting equivalents are being realized.

The Directors believe that the programme served to bring together a wide geographical community for a focussed meeting. The views are clearly only a snapshot of the subject, but the accompanying book and the special issue of the Journal «Low Temperature Physics» (ILTPE -AIP) will act as a reference work in the field. New scientific links have been forged, and plans are being developed to maintain the momentum.