NANOSYSTEMS: PHYSICS, CHEMISTRY, MATHEMATICS, 2013, 4 (6), P. 795–799

ON THE POSSIBILITY OF MAGNETORESISTANCE GOVERNED BY LIGHT

I. Yu. Popov
St. Petersburg National Research University of Information Technologies,
Mechanics and Optics, 49 Kronverkskiy, St. Petersburg, 197101, Russia
popov1955@gmail.com

PACS 75.47.De Giant magnetoresistance

PACS 68.65.Ac Multilayers

PACS 72.80.Le Polymers; organic compounds (including organic semiconductors)

It has been shown that it is possibility to control magnetoresistance by light. The use of light-sensitive banana-shape molecules has been suggested as an engine for varying the thickness or spacer between the magnetic layers. The spacer is filled by a conducting polymer with copper-like conductivity (with inserted bent molecules), ensuring the proper interlayer exchange coupling, which is necessary for transition from a ferromagnetic to an anti-ferromagnetic ordering (and inverse) when the thickness of the spacer changes.

Keywords: magnetoresistance, banana-shape molecule, conducting polymer.

1. Introduction

The discovery of the phenomenon of giant magnetoresistance has greatly accelerated the development of computer memory and related topics. This phenomenon is observed in layered nanostructures consisting of sequentially ordered magnetic and non-magnetic conducting layers [1], [2]. In such sandwich structures, the magnetic layers can have two different orderings: ferromagnetic, FM, (when the magnetic orientation of all layers are aligned) and anti-ferromagnetic, AFM, (when the neighbor layers have opposing magnetic orientations). Correspondingly, there is a spin-dependent electron transport in the system. While electrons with the same spin direction as the layer's magnetization cannot pass through this layer (all the corresponding energy levels are occupied), but it can pass through the magnetic layer with the opposite orientation. In this case, the transition from an anti-ferromagnetic to a ferromagnetic ordering of the layers gives rise to the growth of electric resistance. One can stimulate this transition by switching on an external magnetic field. This is, in short, the idea of giant magnetoresistance. This phenomenon is widely used today for memory elements. This method of giant magnetoresistance control has some disadvantages, e.g., the external magnetic field isn't readily focused. That is why it is interesting to find other ways to effectively control giant magnetoresistance. An interesting possibility is related to the interlayer exchange coupling. It is known that the type of the magnetic layer ordering (FM or AFM) depends on the thickness of the non-magnetic spacer [3]. One can control the type of magnetic ordering by varying this thickness. Particularly, the hydrogenation of the spacer leads to a change in the thickness [4], and, correspondingly, the type of magnetic ordering which causes a jump in the resistance. Unfortunately, hydrogenation can be a very slow process, and one can't use it for memory devices. In the present paper, another way to modify the thickness is suggested. This is based on using photosensitive banana-shape molecules and conducting polymers. The use of light to govern magnetoresistance seems to be very attractive. In this study, we analyze the possibility of its realization.

2. Magnetoresistance governing

There are different ways to change the thickness of thin (polymer) layer excluding mechanical pressure. One is based on the properties of an azobenzene molecule which preferentially absorbs light polarized along its transition dipole axis (long axis of the molecule). Repeated trans-cis-trans isomerization cycles result in a statistical depletion of trans chromophores that lie along the polarization direction, while enriching those lying perpendicular to that direction. Irradiation with unpolarized light can then reverse the process by re-establishing isotropic orientation. The reversibility of the process enables subsequent photo-reorientations.

The trans-cis photoisomerization is the transformation of molecular shape from the rod-like shape of the trans isomer to the bent cis isomer. This transition is reversible. UV light (365 nm wavelength) induced the trans-cis transition, while 465 nm wavelength UV light causes the inverse cis-trans transition. This property is widely used in liquid crystal applications [5–7]. Namely, if these molecules are inserted into a liquid crystal (LC), then the trans isomer stabilizes the phase structure of the LC. Transition to a cis isomer, which acts as an impurity, results in the destruction of ordered mesophase structures, and one observes the phase transition from a nematic to an isotropic LC [8]. Photochemical phase transitions in polymeric liquid crystals (PLCs) have also been induced using spiropyrans, spirooxazines and fulgides [9–11].

The phase-transition behavior of LC mixtures and photochromic spiropyran derivatives, induced by isomerization of the guest molecules, have been investigated. Two types of spiropyran derivatives were employed: normal spiropyrans which are stable in the closed form (spiropyran form; SPF) and open-form (merocyanine form; MCF) stabilized derivatives. These spiropyran derivatives were doped into two LC compounds: 5-cyanobiphenyl (5CB) and 4-butoxyphenyl-4'-ethylcyclohexanecarboxylate (ECH 204). SPF-Stabilized derivatives exhibited photoisomerization behavior from SPF to MCF in LC media which was accompanied by an isotropic (I) to nematic (N) phase transition of the mixtures. On the other hand, an $N \to I$ phase transition of the mixtures was observed when the MCF-stabilized spiropyran doped in both LCs was photoisomerized from MCF to SPF. The result was interpreted in terms of shape anisotropy of the guest molecule associated with each isomer of the spiropyrans.

An interesting example of light-dependent bent angle of a molecule was demonstrated in [12], [13] (see Fig. 1 from [12]). A series of linear polyimides was examined and found to exhibit a polarization-dependent photomechanical response for the wavelengths of 442 nm, 488 nm and 514 nm. The bent angle varies over a wide range (up to 70°). Their results indicate that the isomerization process is about 10 percent efficient; that is, 10% of the incident photon energy $(4 \cdot 10^{-19} J)$ is converted into mechanical work $(\approx 4.5 \cdot 10^{-20} J)$. Photomechanical responses at the macroscopic scale, be that in cantilever or film form, are, to date, significantly less than 1% efficient. As for mechanical stress, it depends on the concentration of the corresponding molecules. The authors obtained the storage modulus (E'= 3.8-6.2 GPa), a stress up to 260 kPa. Such a stress cannot cause a variation of the thickness in the metallic layer (ionic bond is essentially greater). To get an effect, one should use another material. But there is one important feature — this material should have metal-like conductivity. This

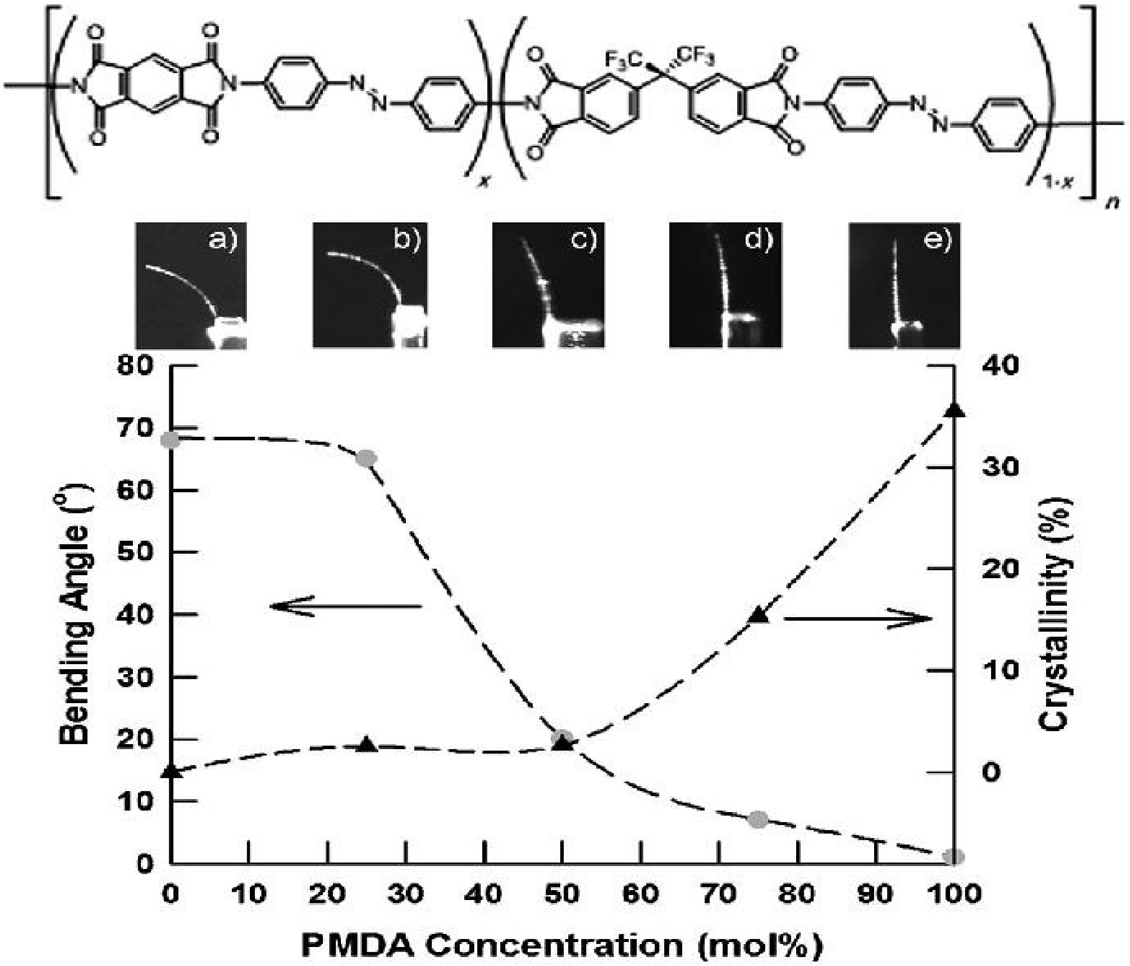

FIG. 1. Summary of photomechanical response (bending angle) and crystallinity as a function of PMDA (pyromellitic dianhydride) concentration for a series of azobenzene-functionalized linear polyimides (generic structure inset). Images of $5mm \cdot 1mm \cdot 0.02mm$ cantilevers composed of azo-PI- 6FDA (a), copolymers of 6FDA/PMDA (azo-coPI-xx) (bd), and azo-PIPMDA (e) after 1 h of irradiation with $\lambda = 442nm$ light polarized parallel to the long axis of the cantilever

is necessary to ensure interlayer exchange coupling [1]. Only under this condition, can one vary the type of magnetic ordering (ferromagnetic or anti-ferromagnetic), which depends on the thickness of the non-magnetic spacer. Fortunately, there are conducting polymers with metal-like conductivity. Particularly, polyacetylene exhibits copper-like conductivity [14]. Currently, it is the only conducting polymer with such properties. This material has environmental instability which is an obstacle for using of this polymer for wiring, but for our purpose it is not crucial. Thus, the spacer should be filled by a conducting polymer having copper-like conductivity with a great number of light sensitive bent molecules inserted. Such a spacer gives one the possibility to control magnetoresistance by light. The procedure is schematically shown on Fig. 2. Namely, light of the proper wavelength causes the variation of the bent angles of banana-shape molecules which are oriented in the appropriate manner (particularly, they can be attached by their ends to the neighboring magnetic layers). The technology (see, e.g., [15]) allowing one to arrange the bent molecules in a proper way between the layers (see Fig. 2) is known. In this situation, changing the angle of the bend leads to variation of the spacer width, and, consequently, to the type of magnetic ordering due to the interlayer exchange coupling. As a result, we get a jump in the magnetoresistance.

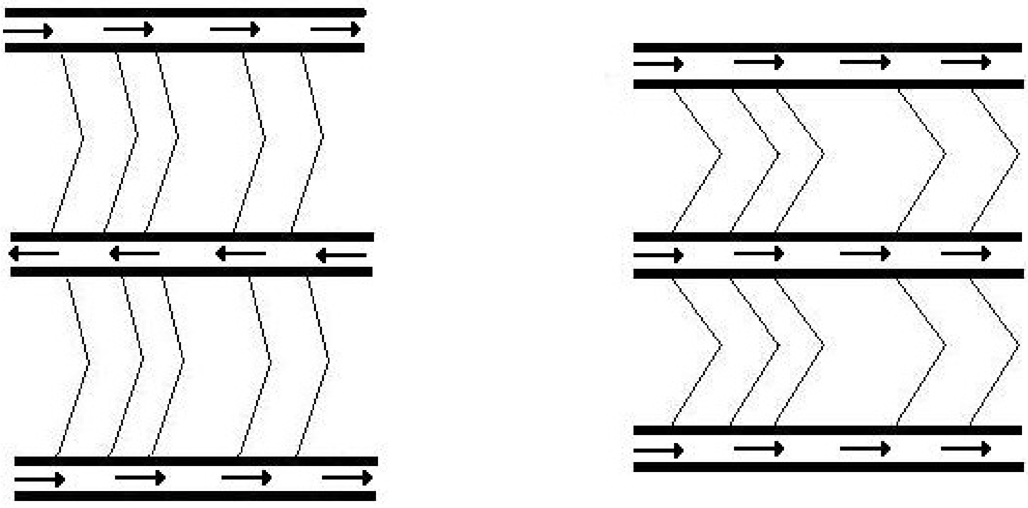

FIG. 2. Arrangement of bent molecules between the magnetic layers. Magnetic layers are strips with arrows, showing the magnetization. Molecules of the conducting polymer filling the spacer aren't shown. Mechanism of thickness governing and the corresponding change of magnetic ordering (left - AFM, right - FM) are schematically shown

Acknowledgements

The work was supported by FTP "Scientific and Educational Human Resources for Innovation-Driven Russia" (contract 16.740.11.0030, grant 2012-1.2.2-12-000-1001-047), grant 11-08-00267 of RFBR and by Program of Development of Leading Russian Universities.

References

[1] P.Grünberg. Layered magnetic structures: facts, figures, future. *J.Phys.: Condens. Matter.*, **13**, P. 7691–7706 (2001).

[2] L.V. Gortinskaya, I.Yu. Popov, E.S. Tesovskaya, V.M. Uzdin. Electronic transport in the multilayers with very thin magnetic layers. *Physica E*, **36**, P. 12–16 (2007).

[3] V.M. Uzdin, N.S. Yartseva, L. Adamowicz. Phase shift of exchange coupling oscilations in magnetic multilayers. *J. Magn. Magn. Mater.*, **203**, P.283–285 (1999).

[4] S. Ostanin, V. M. Uzdin, C. Demangeat, J.M. Wills, M. Alouani and H. Dreysse. Effect of hydrogen on the interlayer exchange coupling in FeOV superlattices. *Phys. Rev.*, **B 61**(7), P. 4870–4876 (2000).

[5] K.Ichimura. Photoalignment of Liquid-Crystal Systems. *Chem. Rev.*, **100**, P. 1847–1874 (2000).

[6] Y. L.Yu, T.Ikeda. Alignment modulation of azobenzene-containing liquid crystal systems by photochemical reactions. *J. Photochem. Photobiol*, C **5**, P. 247–265 (2004).

[7] T.Ikeda. Photomodulation of liquid crystal orientations for photonic applications. *J. Mater. Chem.*, **13**, P. 2037–2057 (2003).

[8] P. M.Hogan, A. R.Tajbakhsh, E. M.Terentjev. UV manipulation of order and macroscopic shape in nematic elastomers. *Phys. Rev. E.*, **65**, P. 041720 (2002).

[9] S.Kurihara, T.Ikeda, S.Tazuke, J. E.Seto. Isothermal phase transition of liquid crystals induced by photoisomerization of doped spiropyrans. *J. Chem. Soc., Faraday Trans.*, **87**, P. 3251–3254 (1991).

[10] I.Cabrera, V.Krongauz. Dynamic ordering of aggregated mesomorphic macromolecules. *Nature*, **326**, P. 582–585 (1987).

[11] I.Cabrera, A.Dittrich, H.Ringsdorf. Thermally Irreversible Photochromic Liquid Crystal Polymers. *Angew. Chem. Int. Ed. Engl.* **30**, P. 76–78 (1991).

[12] K. M. Lee, D. H. Wang, H. Koerner, R. A. Vaia, L.-S. Tan, T. J.White. Enhancement of Photogenerated Mechanical Force in Azobenzene-Functionalized Polyimides. *Angew. Chem.*, **124**, P. 4193–4197 (2012).

[13] D. H. Wang, K. M. Lee, Z. Yu, H. Koerner, R. A. Vaia, T. J.White, L.-S. Tan. Photomechanical Response of Glassy Azobenzene Polyimide Networks. *Macromolecules*, **44**, P. 3840–3846 (2011).

[14] M. Angelopoulos. In: *Handbook of Conducting Polymers.* eds. T.A.Skoteum, R.L.Elsenbaumer, J.R.Reynolds (Marcel Dekker, Inc. New York. 1998), p. 921.

[15] L.-Yu. Wang, H.-Yi Tsai, H.-Ch. Lin. Novel Supramolecular Side-Chain Banana-Shaped Liquid Crystalline Polymers Containing Covalent- and Hydrogen-Bonded Bent Cores. *Macromolecules*, **43**, P. 1277–1288 (2010).