Austin Journal of Biosensors & Bioelectronics

Open Access

Austin Publishing Group

Mini Review

Ferrogels with Magnetic and Electric Properties as Perfect Materials for Biosensors

Fähnle M*

Former Member of the Max Planck Institute for Intelligent Systems, Stuttgart, Germany

***Corresponding author:** Manfred Fähnle, Former Member of the Max Planck Institute for Intelligent Systems, Stuttgart, Schönblickstraße 95, 71272 Renningen, Germany

Received: October 01, 2021; **Accepted:** October 30, 2021; **Published:** November 06, 2021

Abstract

In the present paper the properties of ferrogels which have magnetic and electric properties are discussed. The production of these ferrogels is discussed. It is shown that the shapes and orientations of these ferrogels may be changed on the one hand by the interactions of their magnetic (electric) moments with a non-uniform external magnetic (electric) field, on the other hand by magnetostrictive (electrostrictive) strains. The differences between magnetostrictive and electrostrictive strains are discussed. It is shown that these ferrogels are perfect materials for biosensors.

Biosensors

Biosensors are probes which are implanted in a biological materials and which exhibit a direct coupling with a transducer and an electronic amplifier. By biosensors the magnetic and electric fields appearing in biological materials can be measured. They are therefore used in biological technologies and in medical technologies. In Ref [1]. The functions of magnetic particles as Nano sensors are discussed. I ia asked how far away we are we to implement them into clinical practice. Several kinds of biosensors are described. In the present paper it is discussed that ferrogels with magnetic and electric properties are perfect materials for biosensors. I want to tell this the community of people working on biosensors, and to ask them whether these ferrogels can be used in the human body.

Magnetic Properties of Ferrogels

In Ref [2]. Magnetic-field sensitive gels (ferrogels) have been prepared by introducing single-domain magnetite (Fe_3O_4) particles of colloidal size into chemically crosslinked hydrogels. The influence of a non-uniform external magnetic field on the shapes of the gel tubes and the possibility to induce elongations and contractions by means of a magnetic field produced by an electromagnet has been demonstrated. It has been shown that both the concentrations of the magnetite particles as well as the crosslinking density of the hydrogels play an essential rule in the magnetoelastic behavior.

A magnetite particle has a magnetic moment *m*. In a non-uniform magnetic field, the magnetic moment experiences a force,

$$F = \text{grad}\ (m*B) \qquad (1)$$

This has been used in the Stern-Gerlach experiment [3] to demonstrate by the splitting of a beam of Ag atoms in a non-uniform magnetic field that an electron carries a magnetic moment of the magnitude of a Bohr magneton. By the force the shapes of the gel tubes is changed, and elongations and contractions appear.

In the present paper it is discussed that the shapes may be changed by two effects. First, by the force exerted on the magnetite particles by an inhomogeneous magnetic field, and - in addition-also by magnetostrictive effects. The magnetite particles have magnetic moments and thus magnetizations. In systems with a magnetization there is a magnetoelastic interaction of the magnetization with the lattice, and this generates magnetostriction [4]. The magnetostrictive effect changes the extensions of the system, and as a result it changes the shape of the system. In multi-domain systems there are domains in the same system with different orientations of the respective magnetization. When applying an external magnetic field, the domains with a respective magnetization direction close to the direction of the external field are energetically preferred over domains with the respective magnetization directions far from the direction of the external magnetic field, and this produces a dominance of the preferred domains. Finally, when increasing the magnitude of the external field even more, then the magnetizations in the domains are rotated out of their easy axis directions and are more aligned parallel to the external field, for very strong fields they are nearly completely parallel to the external magnetic field, and a saturation magnetostriction is reached. In the ferrogels discussed in Ref [1]. There are single-domain magnetite particles. As discussed above, the external magnetic field rotates the various magnetizations of the single-domain particles towards the direction of the external magnetic field, giving a saturation magnetostriction for very large fields. The saturation magnetostriction depends on the values of magnetostriction constants [4]. In transition metals the magnetostrictive strains are rather small, typically 10^{-5}. In compounds containing rare-earth atoms like $TbFe_2$ the magnetostrictive strains are typically an order of magnitude larger. The values of the magnetostriction constants are determined by electronic effects, e.g., by the electron density of states at the Fermi level. It has been shown [5] for FeGa alloys that this density of states is strongly determined by the magnitude of the spin-orbit coupling. Furthermore, it is discussed that at surface atoms or at near-surface atoms the spin-orbit coupling is stronger than at bulk atoms, because of the reduced symmetry at these sites [6]. For temperatures above the Verwey temperature of about 120 K, magnetite has a cubic symmetry. Then the magnitude of the magnetostriction is determined by the magnetostriction constants Δ_{100} and Δ_{111} [4]. Because nanoparticles have many surface or near-surface atoms, the spin-orbit coupling is large, and this has – as discussed above - a great influence on the electron density of states and hence on the values of the two magnetostriction constants which are much larger than those in bulk materials. Therefore there is

Citation: Fähnle M. Ferrogels with Magnetic and Electric Properties as Perfect Materials for Biosensors. Austin J Biosens & Bioelectron. 2021; 6(1): 1037.

a giant magnetostriction in magnetite nanoparticles. In Ref. 6 it was shown that the magnetostriction is determined by quasiplastic strains ε^{Q} in which the magnetization components $M_i(H)$ enter, where H is the external magnetic field.. When the magnetization directions in all nanoparticles are aligned to each other, then the magnetostrictive strains have the same orientations in all nanoparticles and a saturation magnetization appears. However, this requires very high fields, not just because high fields are needed to rotate the magnetizations out of their easy axis directions. It is discussed in Ref [2]. That there are dipolar interactions between the nanoparticles, and they result in the fact that the magnetizations are not completely aligned, especially for not two large external magnetic fields. As a result, the global magnetostriction of the ensemble of nanoparticles is smaller than its maximum value. When increasing the external field even more, the magnetizations in the various nanoparticles become more aligned, i.e., the magnetostriction depends strongly on the value of the external magnetic field and reaches a maximum only for very strong magnetic fields.

Electric Properties of Ferrogels

Some ferrogels have also electric properties, i.e., they contain electric dipoles. Again the shapes and orientations of these particles are determined, on the one hand by applying inhomogeneous electric fields, on the other hand by electrostrictive and dipolar interactions. In an inhomogeneous electric field the electric moments m experience a force,

$$F = \text{grad}\ (m^*B) \qquad (2)$$

Again, the forms and the orientations of the ferrogels are determined on the one hand by their interactions with inhomogeneous electric fields, and the other hand by electrostrictive and dipolar forces. The equation for the dipolar forces between the electric moments has the same form as the equation for the dipolar interactions between the electric moments. The electrostriction is different from the magnetostriction. The magnetostriction depends on the magnetization in a nonlinear manner [4]. For the electrostriction there are two parts. One part depends quadratic ally on the dielectric polarization. It appears for all crystal structures. The second part is called piezostriction. It depends on the dielectric polarization in a linear manner, and it appears only in crystals with the 20 piezoelectric symmetry classes.

References

1. Simon Doswald, et al. Biochemical functionality of magnetic particles as nanosensors: how far away are we to implement them into clinical practice? J. Nanobiotechnology. 2019; 17: 73.
2. M Zrinyi, L Barsi, A Büki. Ferrogel: a new magneto-controlled elastic medium. Polymer Gels and Networks. 1997; 5: 415-427.
3. W Gerlach, O Stern. Zeitschrift für Physik. 1922; 9: 349 -352 and 353-355.
4. H Kronmüller and M Fähnle, Micromagnetism and the Microstructure of Ferromagnetic Solids. Cambridge University Press, Cambridge, UK. 2003.
5. R Wu. Origin of large magnetostriction in FeGa alloys. Appl. Phys. 2002; 91: 7358.
6. CFJ Flipse, GB Rouwder and FMF de Groot. European Physics Journal. 1999; 39: 479.
7. A Hubert and R Schäfer. Micromagnetic Domains; the Analysis of Microstructures, Springer Verlag, Berlin, Heidelberg. 1998.