INVESTIGATION OF DNA-MAGNETIC NANOPARTICLE INTERACTION BY MAGNETO-OPTICAL LINEAR DICHROISM

Selma Önal KÖKLÜ[1], İsmail YARİÇİ [1*], Yavuz ÖZTÜRK [1]

[1]Ege University, Electrical and Electronics Engineering, İzmir, Turkey
selmaonalkoklu@gmail.com,yariciismail@gmail.com, yavuz.ozturk@ege.edu.tr

Abstract: *In this study, interaction of produced magnetic nanoparticles (MNPs) with DNA was investigated by using designed magneto-optical linear dichroism (MOLD) measurement system.* Fe_3O_4 *nanoparticles (NPs), produced by using co-precipitation method were characterized by means of structure, magnetic, and size distribution. These NPs coated with oleic acid and Tetramethylammoniumhydroxide (TMA) in water and ethanol. Change of the linear dichroism property of dissolved NPs in the fluid under applied magnetic field was observed due to the interaction of produced MNPs with DNA. Obtained results were shown that it is possible to develop a DNA sensor by using MNPs and MOLD effect.*

Keywords: *Magneto-optical linear dichroism, DNA, Magnetic nanoparticles MNPs.*

1. Introduction

Nanoparticles (NPs), defined as particles with dimensions of 100 nm and below, form the basis of nanotechnology. MNPs are promising for many areas such as optics, electronics, medicine, drug delivery, diagnosis and treatment of diseases due to the behavior against the magnetic field and their adjustable dimensions. Nanotechnology has provided significant advantages for scientists in the field of many healthcare and life sciences, both in the cellular dimension and molecular level [1-5]. Furthermore, they are biocompatible with molecules such as DNA and Protein; they can be linked to this kind of structures [6]. They also have many potential applications like cancer diagnosis and treatment, hyperthermia, DNA detection, DNA isolation, magnetic resonance imaging and tissue therapy [7].

Nowadays, biocompatible materials comprised of the combination of DNA and MNPs attract particular attention with regard to their design. The administration of these systems is extremely important for the development of areas such as nano-electronic, biomedical diagnosis and treatment (development of sensitive biosensors and effective pharmaceuticals). The combination of MNPs with biological molecules and especially nucleic acids allows the development of various nanobiohybrid systems which have unique magnetic properties and biological selectivity [8,9].

DNA-MNP interaction may show different magneto optic properties in the liquid under applied magnetic field [10]. Although the magnetic fluids (suspended MNPs in a carrier liquid) are isotropic; with the applied external magnetic field they show anisotropic characteristic and exhibit birefringence effects and linear and circular dichroism effects. Such interactions under magnetic field are called magneto-optic effects [11]. The MOLD effect is explained by the formation of chain structures of MNPs in liquid under applied magnetic field [12,13]. Every particle in the electric field under this cluster is considered to be oscillating dipoles. These dipoles interact to each other because of their closeness. This interaction is asymmetrical depending on the direction of the light beam. This asymmetry creates the optical anisotropy effect that lead to linear dicroishm and linear birefringence effect in the magnetic fluid [11].

There are a few studies focused on DNA-magnetic fluid interaction and magneto-optical effects [10]. Circular-dichroism effect is generally used to investigate molecules such as DNA and proteins [14]. However, this DNA-related measurement method only works in the ultraviolet (UV) region [14]. So it is important to develop measurement methods in the visible region of light. With this motivation, in this study, MOLD effect of the influence of single stranded and double stranded DNA-MNPs solutions was studied. For this purpose, a MOLD measurement system was designed. Afterwards, the size, structure and magnetic properties of produced MNPs were characterized. The MNPs were coated with oleic acid and TMA in order to prevent agglomeration. The coated NPs were suspended in water and then the MOLD properties of interaction with single stranded, double stranded DNA were examined.

Received on: 31.01.2017
Accepted on: 14.03.2017

2. Material and Method

2.1. Production of MNPs

The co-precipitation method was used for synthesis of MNPs. During the production, as the first step $FeCl_3.6H_2O$ (0.01 mol) and $FeCl_2.4H_2O$ (0.02 mol) were dissolved in pure water and in a 1M HCl prepared solution in separate cups as separate solutions. Then they are mixed with molar ratios of 1: 2. The prepared solutions were stirred in a nitrogen gas atmosphere for 30 minutes, after that in order to adjust the pH value of solution and to ensure the continuity of the synthesis; ammonium was added into the mixture. Ammonium was added until the pH value was 10, which is accepted optimum value for the solution [15]. 15 minutes after the chemical reaction had started; the solution was washed 3 times with 5% ammonium solution to prevent the surface charge density of the particles from decreasing and the particles to avoid agglomeration. Some of the magnetic particles precipitated on the bottom were suspended in pure water by coating with tetramethylammoniumhydroxide (TMA) and oleic acid.

2.2. Analysis of MNPs

Structural analysis of the synthesized NPs, size distribution of the NPs in the liquid, and magnetic and optical properties of the NPs were characterized using X-ray diffraction (XRD), dynamic light scattering (DLS) and Vibration Sample Magnetometer (VSM) devices, respectively.

2.3. MOLD Measurement System

A magneto-optic experimental setup designed for this study was used to investigate the polarization-dependent transmission changes of the magnetic liquid at different magnetic field values. Magnetic liquid were prepared to include single stranded DNA and produced magnetic liquid.

A fiber coupled tungsten lamp used to obtain wide wavelength range light source. The output of light source polarized using Glan-Thomson type polarizer. Light was passed through the lens system to the sample and spectrometer. The magnetic field was generated by an electromagnet controlled with the adjustable current source.

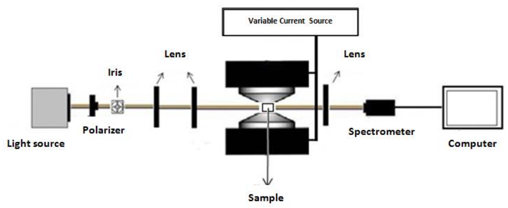


Figure 1. The designed magneto-optical measurement system

Depending on the polarization direction and the magnetic field values, the amount of transmitted light through the sample was measured at a wavelength range of 500 nm-1000 nm by USB-4000-UV-VIS spectrometer.

3. Experimantal Results

Structural analyzes of the produced MNPs were taken by a Philips Expert 1830 model XRD. The XRD result of the sample is given in Fig.2. As seen in Fig. 2, the structure of sample is Fe_3O_4.

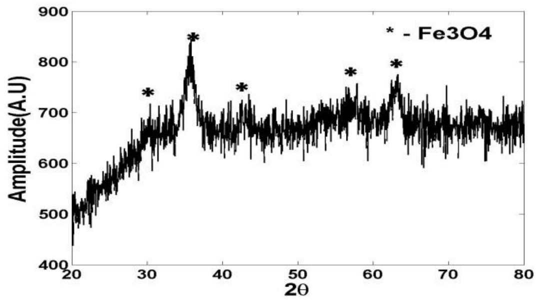


Figure 2. X- ray diffraction pattern of MNPs

The size distributions of MNPs in solution were determined using a Zetasizer 4 Nano S-Malvern DLS (Dynamic Light Scattering). According to the DLS results, size of the produced magnetic particle and the standard deviation was determined as 34 nm and 17 nm respectively.

The magnetic analysis of the NPs was performed by using Lakeshore 736, 7400 VSM instrument. As a result of the measurements, it is measured that the coercivity of NPs is low and the particles show superparamagnetic behavior. The saturation magnetization value of the particle in our study was found to be 62 emu / g. Saturation magnetization value of macro size solid Fe_3O_4 is 93 emu /g [16]. For NPs, the saturation magnetization is generally smaller than the solid one. One of the reasons for this is explained by the negative effect of magnetization of the non-magnetic layer on the surfaces of NPs [16].

The optical transmission test for the magnetic fluid mixture prepared with oleic acid and ethyl alcohol was carried out as shown in Fig.3. It is seen that the light transmission perpendicularly to the direction of the applied magnetic field (P90) and parallel to the magnetic field (P0) under the magnetic field is different. Thus, the MOLD effect appears clearly. In many studies on this subject, this effect is explained by the chain structure of the particles under the magnetic field [11]. Electric dipole interactions between the MNPs forming the chain structure cause different absorption.

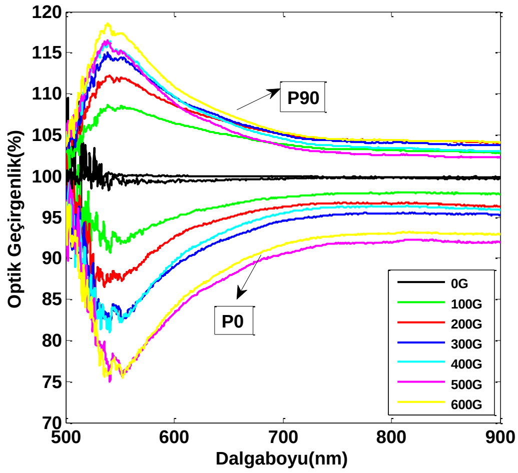


Figure 3. The optical transmission test for the magnetic fluid mixture prepared with oleic acid and ethyl alcohol was carried out

20 mg single-stranded herringbone DNA was mixed into the magnetic fluid. The optical transmittance of this mixture changed due to polarization under applied field. This optical transmittance change for different polarization under applied magnetic field was shown in Fig.4 and Fig.5. Optical transmission increases at different amounts depending on polarization under the same external magnetic fields. For example, the P0 polarization under the 400G external field has a maximum optical transmittance of 123%, but this value remains at 111% for P90. The results clearly state that the MOLD effect is different for magnetic fluid with and without single stranded DNA. The optical transmission increases for both polarizations under the applied magnetic field. The optical absorption increase which is explained by the formation of the chain structures shown in Fig.3 was not observed for the polarization of P0 in Fig.5.

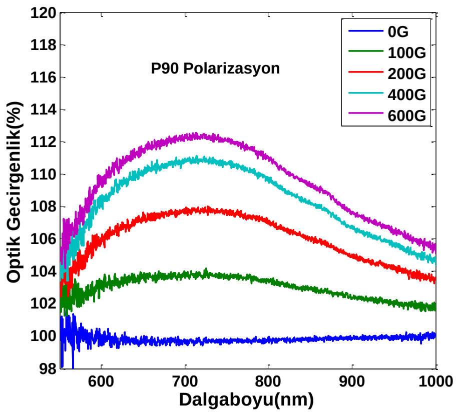


Figure 4. The wavelength-dependent optical transmission of magnetic fluid containing 20 mg single stranded DNA in P90 polarity out

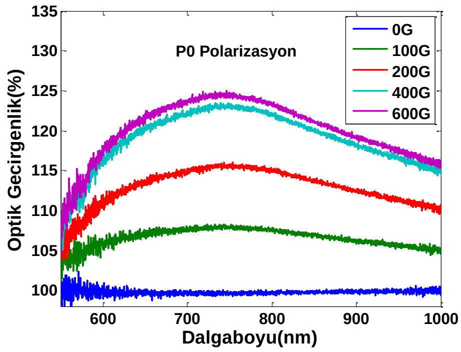
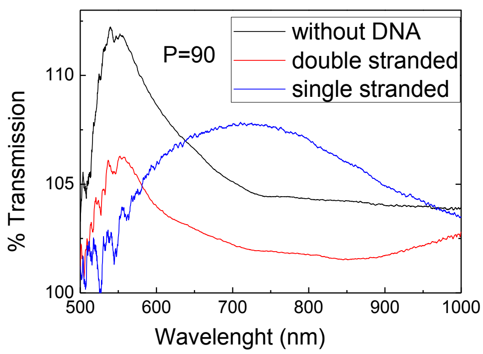


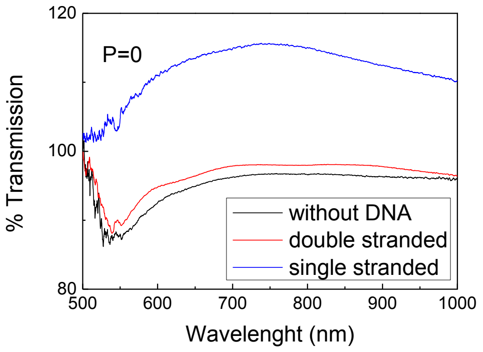
Figure 4. The wavelength-dependent optical transmission of magnetic fluid containing 20 mg single stranded DNA in P0 polarity out

The same study also was repeated for double stranded DNA and obtained results were shown in another study [15].

In order to compare the change in the transmission of light of single stranded samples, double stranded samples and samples which do not contain DNA molecules as a result of polarization, magnetic fluids which contain 20 mg single - 20 mg double stranded DNA in each and fluid samples which do not contain DNA were shown on the same graphic under 100 Gauss fixed magnetic field. Magnetic particles bind with the double stranded DNA less than the single stranded because it has a helix structure. Changes related to polarization in double stranded DNA-magnetic fluid mixture show that the chain structure is formed in the mixture. Transmission of light related to polarization is lower compared to the fluid which does not contain DNA. Changes related to polarization are considerably low in the single stranded version. This situation shows that the transmission of light related to polarization in the chain structure formation of the single stranded mixture is prevented. This result may be explained with the prevention of the chain structure and reduction of the interaction between the magnetic particles in the single stranded structure which we explained before. According to us, the interaction between magnetic particles in the single stranded mixture mostly causes clusters.



(a)



(b)

Figure 6. Transmission spectrum of magnetic liquid that are without DNA, 20mg double- stranded DNA and single-stranded DNA under 100G magnetic field. a) P= 90 polarization, b) P=0 polarization

These observations can be explained by the interaction between DNA and NPs which prevents the chain formation. The study conducted by Byrne et al. (2004) examined the Fe3O4 NPs synthesized with the co-precipitation inside a solvent containing a single strand denature and double helix herring DNA and it was observed that the NPs were bonded to the DNA molecule with the formation of Fe-O-P bonds [17]. Transmission increase at both polarizations can be explained by formation of another structure of MNPs instead of chain structure. It is clear that the new structures of NPs open the light path and increase transmission due to the single stranded DNA in liquid.

5. Conclusions

In this study, MNPs were synthesized using the coprecipitation method with a mean particle size of 34 nm and a saturation magnetization of 62 nm. In order to obtain the measurements, the appropriate experimental set up was prepared and the MOLD effect was investigated for with single- stranded DNA, double stranded DNA and without DNA. The DNA-MNPs solution obtained was examined for the change in polarization of the mixture of single and double stranded DNA and magnetic fluid. The MOLD effect is shown. As the magnetic field increases, the chain structure is reinforced and the impact of linear dichroism is determined to increase.

When DNA is added to the reference fluid, it is seen that the effects related to polarization in the transmission of light is reduced. Together with the NPs in the fluid, the presence of DNA affects the chain formation mechanism of the MNPs. As the DNA amount increases, the interaction between the MNPs decreases.

Along with the measurements made with double helix DNA; single stranded DNA which is very important for the diagnosis of certain diseases, was examined to show the changes in the transmission of light under the magnetic field and related to polarization with the help of the same experimental apparatus. When the single stranded, double stranded DNA containing samples and the samples that do not contain DNA molecule are compared, it is revealed that the changes based on polarization in the double helix DNA-magnetic fluid structure show the formation of a chain structure. However, transmission of light related to polarization is lower compared to the fluid which does not contain DNA. Changes related to polarization is considerably low in the single stranded version.The obtained results will contribute to the development of studies with regard to the use of DNA-MNPs mixture as DNA sensor or biosensor.

6. References

[1] R. E. Hernandez , A. Baeza & M.V. Regi , “Smart Drug Delivery through DNA/Magnetic Nanoparticle Gates.”, *ACS Nano,* 5(2), pp.1259-1264. 2011.

[2] Ge, Jianping, et al. "Superparamagnetic magnetite colloidal nanocrystal clusters." *Angewandte Chemie International Edition* 46.23 ,4342-4345, 2007

[3] G.Jianping,Y.Hu, and Y.Yin.,"Highly tunable superparamagnetic colloidal photonic crystals." *Angewandte Chemie*, 119.39, 7572-7575, 2007

[4] S.Mostafa, et al. "Terahertz Faraday rotation in a magnetic liquid: High magneto-optical figure of merit and broadband operation in a ferrofluid." *Applied Physics Letters* 100.24 ,241107. 2012

[5] J., Min Sook, et al. "Methodological considerations of electron spin resonance spin trapping techniques for measuring reactive oxygen species generated from metal oxide nanomaterials." *Scientific reports* 6 (2016).

[6] M.T. Pooja ,V.Komal, A.D. Vida, & R.S. Shree, “Functionalized Gold Nanoparticles and Their Biomedical Applications.” *Nanomaterials*, s.31-63 ,2011.

[7] Melancon, M., & Lu, W. “Gold-Based Magneto-Optic Nanostructures: Challenges for In Vivo Applications in Cancer Diagnostics and Therapy.” *Mater Res. Bull*, s.415-421 ,2009

[8] Pershina, Alexandra Gennadievna, A. E. Sazonov, and Victor Dmitrievich Filimonov. "Magnetic nanoparticles–DNA interactions: design and applications of nanobiohybrid systems." *Russian Chemical Reviews*, 83.4, 299, 2014.

[9] Tiwari, A. P., S. J. Ghosh, and S. H. Pawar. "Biomedical applications based on magnetic nanoparticles: DNA interactions." *Analytical Methods* 7.24,10109-10120,2015

[10] S.Y. Park, H. Handa, and A. Sandhu. "Magneto-optical biosensing platform based on light scattering from self-assembled chains of functionalized rotating magnetic beads." *Nano letters* 10.2 ,446-451, 2009.

[11] Xu, M., and Ridler, P. J., , “Linear dichroism and birefringence effects in magnetic fluids”, *American Institute of Physics*. 82, 326, 1997

[12] Inaba, N., et al. "Magneto-optical absorption in infrared region for magnetic fluid thin film." *IEEE Transactions on Magnetics 25*.5 ,3866-3868. 1989

[13] Rousan, Akram A., Hassan M. El-Ghanem, and Nihad A. Yusuf. "Faraday rotation and chain formation in magnetic fluids." *IEEE Transactions on Magnetics* 25.4 ,3121-3124, 1989

[14] Ranjbar, Bijan, and Pooria Gill. "Circular Dichroism Techniques: Biomolecular and Nanostructural Analyses- A Review." *Chemical biology & drug design* 74.2 ,101-120,2009

[15] Köklü, S.Ö., Yariçi, İ., and Öztürk, Y., “Investigation of DNA-Magnetic Nanoparticle Interaction by Magneto-Optical Linear Dichroism “, *Biyomut16, 2016*

[16] Cao, S. W., Zhu, Y. J., & Chang, J. “Fe3O4 polyhedral nanoparticles with a high magnetization synthesized in mixed solvent ethylene glycol–water system.” *New J. Chem*., s.1526–1530 ,2008

[17] Byrne S. J.,Corr S. A., Gun’ko Y. K., Kelly J. M., Brougham D. F., and Ghosh S..” Magnetic nanoparticle assemblies on denatured DNA show unusual magnetic relaxivity and Potential applications for MRI”, *Chem. Commun*., 2560, 2004

Selma KÖKLÜ was born in Alaşehir district of Manisa. Selma has enrolled at university in 2007 and graduated with an honour degree-3rd of department from the department of physics at Izmir Institute of Technology in 2012. In the same years, she studied extra course in electrical and electronics engineering department. She did willing internship at Atomic Energy Institute of Turkey in Istanbul. In 2013 Selma applied to Ege University for master degree in Biomedical Technologies and completed her master's degree in 2016. In the master thesis she investigated the active attachment of DNA and magnetic nanoparticles and magneto-optical effects of single-stranded and double-stranded DNA patterns by polarization optics.

İsmail YARİÇİ was born in Ağrı, Turkey. He received the B.E., M.E., in Electrical & Electronics Engineering, Izmir Institute of Technology (IZTECH), Turkey, in 2012, and Ege University, Turkey, in 2015, respectively. He is currently a Ph.D. student in Ege University.In 2012 he joined the department of Electrical and Electronics Engineering, Ege University, as a research assistant and he is currently working there. His current research interest include magneto-optic measurement systems, biomedical optic and electromagnetic teori.

Yavuz Öztürk was born in Kayseri , Turkey. Yavuz Öztürk received his MSc (2004) and PhD degrees (2010) in Electrics and Electronics Engineering from Ege University (İzmir, Turkey). He was a postdoctoral fellow at INRS-EMT between 2010-2012. Since 2012, he is a assistant proffesor at Ege University. He studied the fabrication and characterization of garnet type magneto-optical films, magneto-optical measurement systems, magnetic material properties and spin dynamics.