Magnetic system design for investigation of magneto-optical properties of objects in strong magnetic field in terahertz frequency range

S E Azbite, A K Denisultanov, M K Khodzitsky
Department of Photonics and Optical Information Technologies, ITMO University, 49 Kronverkisky av., St. Petersburg, 197101 Russian Federation
E-mail: azbite@mail.ru, alaudi.denisultanov@gmail.com, khodzitskiy@yandex.ru

Abstract. A strong localized magnetic field hemispherical system at room temperature was proposed for application in terahertz magnetooptics, magneto-resonance spectroscopy and magneto-tunable devices. The most effective and suitable structural and material parameters of the system were estimated.

1. Introduction
As known, many advanced scientific experiments need a strong magnetic fields usage [1-4]. For example, properties graphene, which has a huge potential in practice applications [5-9], strongly depend on influence of external temperature and magnetic field [10-12]. For generation of strong magnetic fields electromagnets and superconductor materials are often used, but these systems are not always suitable and energy-consuming for their usage in experimental setups. Therefore, this paper is dedicated to static magnetic system design with the strong magnetic field for the experimental investigation of magneto-dependent graphene properties such as conductivity in terahertz frequency range.

2. Magnetic system parameters and configurations
In the paper [13] the several magnetic system design types are investigated and according to the results hemispherical magnetic system has the strongest magnetic field. This hemispherical system is constructed by equal magnetic segments and a cone underneath the structure. This system is shown in Figure 1.

Magnetic field strength of the system can be found by the following expression:

\[ H(\alpha, \phi_1, \phi_2) = \frac{2\pi \sigma_{av} \sin 2\alpha + 2n \cdot 2M_s(\sigma_1 \sin \alpha + \sigma_2(1 - \sin \alpha))}{\ln(R/r)} \]

where \( R \) is a magnetic system radius, \( r = (x^2 + y^2)^{1/2} \) is the distance of a point from the origin to the observer point, \( M_s \) is a saturation magnetization, \( \alpha \) is a angle at the cone vertex, \( \phi_1 \) and \( \phi_2 \) are angles between vector \( M_s \) and cone axis, \( n \) is a segments number, the average density of...
Figure 1. Hemispherical static magnetic system. Coordinate scale in mm units.

The charge densities at the boundaries between the magnet sectors $\sigma_1 = \sin(\pi/n) \sin \phi_1$ and $\sigma_2 = \sin(\pi/n) \sin \phi_2$. For the segments number $n=8$ the parameters $\alpha = 54^\circ, \phi_1 = -107^\circ$ and $\phi_2 = 14^\circ$ allow to obtain the most effective system design [13]. For the hemisphere radius $R=50$ mm, the segments number $n=8$ and the saturation magnetization $M_s = 1280$ Gs the magnetic field $H$ dispersion has the following form (Figure 2):

\[
\sigma_{av} = M_s [\arccos(\sin(\alpha + \phi_1) - \frac{\pi/n}{6} \cos \alpha \sin \phi_1)
- \arccos(\sin(\alpha + \phi_2) - \frac{\pi/n}{6} \cos \alpha \sin \phi_2)]
\]

(2)

Figure 2. The magnetic field mapping for the investigated system.
2.1. Material
For the simulation the material with the highest magnetization value was chosen. It was $Nd_{2}Fe_{14}B$ with magnetization $M_s = 1280$ Gs [14]. The magnetic systems consisted of this material can be made by industrial firms on request. In another words, nowadays it is no problem to get this system for experimental proposes.

2.2. Segments number
The segments number $n$ of the magnetic system is able to impact on the magnetic field strength. The dependance of the magnetic field $H$ on the coordinate $X$ was simulated at the coordinate $Y = 0$. The comparison of the impact of different segments number is demonstrated in Figure 3:

![Figure 3. Dependence of the magnetic field strength on the segments number.](image)

As seen in Figure 3, by increasing of the segments number the magnetic system saturation comes after $n = 8$. It is worth noting, the assembling of 16 segments is harder than 8, so $n = 8$ is the most optimal segments number.

2.3. Magnetic field for various radius
The next step is the definition of the system radius influence on the magnetic field distribution. In simulation segments number $n=8$ and magnetization $M_s = 1280$ Gs were used. In Figure 4 and Figure 5 the magnetic field distribution for various radius are shown.

By the magnetic field distribution behavior in Figure 5 it can be concluded, that by increasing of the system radius the magnetic field distribution smooths. Too much smoother field is more suitable for a research, because in every point more precise magnetic field value is obtained. But we are limited by experimental setup proportions, therefore the radius of magnetic system should be agree with the system compactness.

3. Conclusions
In this paper analytical simulation of hemispherical magnetic system with the strong magnetic field was investigated. The influence of the magnetic system configuration parameters such as the system radius $R$, the magnetization $M_s$ and the segments number $n$ on the magnetic
field distribution was demonstrated. This type magnetic system with most suitable parameters ($R = 50 \text{ mm}$, $M_s = 1280 \text{ Gs}$ and $n=8$) will be used in terahertz spectrometer setup for experiments due to simplicity in using (a sample is shifted along the magnetic system surface) and availability of magnetic field map, that allows to know magnetic field value in every point.

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4. References
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