FERROMAGNETIC RESONANCE IN EPITAXIAL FILMS OF Al-SUBSTITUTED BARIUM HEXAFERRITE

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We present the results of experimental investigations of the ferromagnetic resonance (FMR) in epitaxial films of Al-substituted barium hexaferrite $BaFe_{12-x}Al_xO_{19}$ ($0 \leq x \leq 1.8$) grown on the strontium hexagallate ($SrGa_{12}O_{19}$) substrates. The studies were performed on the R1-32 and R1-33 measurement lines using the waveguide method. As a result of the measurements, the following magnetic parameters were determined: a field of magnetocrystalline anisotropy H_a, a ferromagnetic resonance linewidth $2\Delta H$, and a resonance field $H_{\rm res}$. It has been shown that the substitution level x strongly influences the magnetic parameters of films. The value of the anisotropy field is by about 10 kOe greater than that in the parent (undoped) epitaxial films of barium hexaferrite. The magnetic parameters for the parent and substituted epitaxial films of barium hexaferrite are compared and discussed.

An increase in the anisotropy fields makes it prospective to develop devices which, being based on hexaferrites, operate in a frequency range 40 – 140 GHz. There are no other materials that are able to compete with hexaferrites in this frequency range [1]. However, for a series of applications, the operating materials should have not only high values of H_a, but also weak losses, i.e. a narrow FMR line. Magnetic losses in hexaferrites are still high in comparison with those in yttrium iron garnet. Nevertheless, a possibility to change the saturation magnetization $4\pi M$ as well as the value of H_a makes it easy to control the operation frequency range for the devices based on hexaferrite-containing elements [2]. The field of crystallographic anisotropy is 17 kOe for undoped barium hexaferrite and 19 kOe for Sr-doped one. Ultrahigh frequency properties of the single crystals of Ti- and Co-doped barium hexaferrites were studied in work [3]. The spectra of magnetic waves and oscillations as functions of both the value and direction of the bias magnetic field H_0 were investigated for various levels of doping x. It was shown that such substitutions strongly diminish the value of the anisotropy field. The magnetic spectra for barium hexaferrite plates magnetized along the easy direction and having either the plane-parallel or cylindrical domain structures were studied in papers [4—5]. Bulk aluminum-substituted single crystals were investigated in work [6] which presented the saturation magnetization $4\pi M$ measured at room temperature as a function of x. It was shown that the value of $4\pi M$ linearly decreases with increase in x. Contrary to these works which were concentrated on studying the plates 30 – 40 μm in thickness, we worked with the epitaxial films which were 3 – 4 μm in thickness, but their FMR signal intensity was not inferior to that of the plates. It was shown that, by means of the substitution of Al^{3+} for Fe^{3+}, the anisotropy field may be increased up to 30 kOe [6]. This work is aimed at studying the effect of the substitution level x on the magnetic parameters of the epitaxial films of barium hexaferrite.

The investigations of magnetic spectra were performed in a frequency range 49 – 79 GHz using a setup with the R1-32 and R1-33 measurement lines. At a fixed frequency, the traveling-wave factor (TWF) was measured as a function of the external magnetic field H_0, whose value was changed discretely (point by point). The measured TWFs reflected the total losses in the waveguide transmission line containing the specimens under investigation. The specimens 3×2 mm in size grown on the strontium hexagallate substrate 400 μm in thickness were glued with one side to a short circuitor, and put in the waveguide measuring section. The latter was placed between the electromagnet poles in such a way that the film plane was perpendicular to the direction of the external magnetic field (H_a is perpendicular to the film plane).

The field dependences of the resonant absorption measured at a frequency of 79.5 GHz for specimen No. 1 and at 75 GHz for specimen No. 2 are shown in Figs. 1 and 2, respectively. The former specimen is a $BaFe_{12-x}Al_xO_{19}$ epitaxial film 4 μm in thickness with the substitution level $x = 1.8$, whereas the latter one is 3 μm in thickness with $x = 1.6$. Fig. 3 shows the FMR absorption curve at 49 GHz for the epitaxial film of undoped barium hexaferrite (specimen No. 5).

Let us describe a procedure of the determination of the anisotropy field for these films. First, the actual substitution level x was found from the chemical

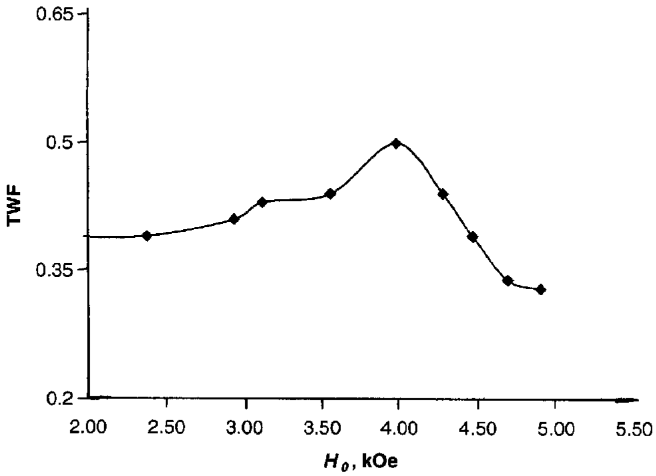

Fig. 1

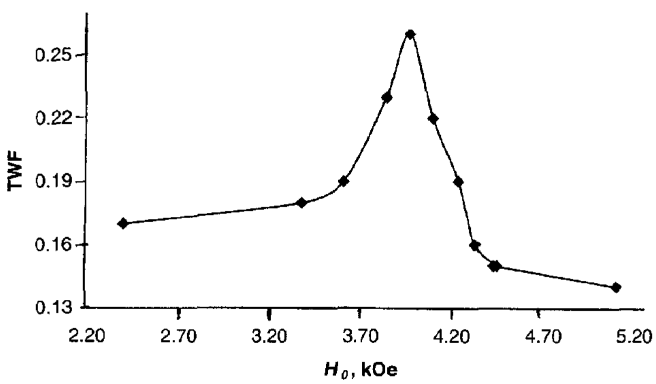

Fig. 2

analysis, and then H_a was calculated from the expression

$$H_a = \frac{\omega_o}{\gamma} - H_0 + 4\pi M, \qquad (1)$$

taking into account that the magnetization M is a function of x. M linearly decreases with increase in x and equals zero at $x = 4.2$:

$$M(x) = M(1 - x/4.2). \qquad (2)$$

The values of ω_0 and H_0 are obtained from the experiment. The magnetization of undoped barium hexaferrite is 0.375 kGs [6]. Alternatively, for the substituted films, the value of $4\pi M$ was also determined from the value of the external magnetic field which made the magnetic bubble (MB) structure disappear, provided that the field was applied along the film normal. The value of the external magnetic field, at which the high- and low-frequency branches of the spectra of the MB structure are joined, was taken as a criterion for the domain structure disappearance. This is an additional

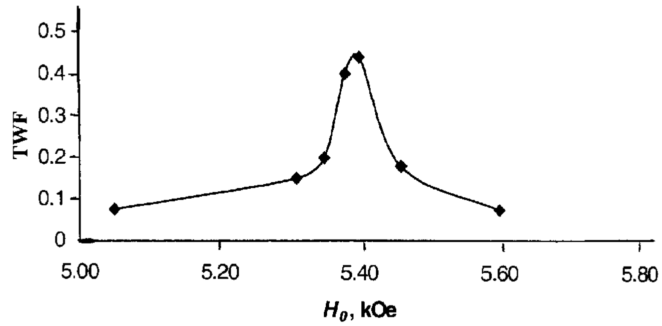

Fig. 3

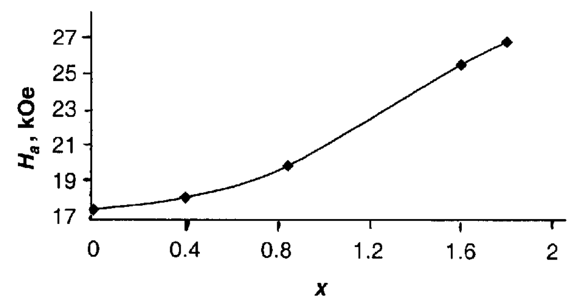

Fig. 4

method of the $4\pi M$ determination. In this case, however, H_0 should have a value which is sufficient for the film saturation.

The table presents the H_a values calculated according to the above procedures, as well as values of $2\Delta H$ and $H_{\rm res}$ determined from the experiment,for five specimens studied.

Specimen N5 is the film of undoped barium hexaferrite which serves as a reference specimen. It is seen that the substitution level strongly influences H_a.

Fig. 4 shows H_a for the epitaxial films of Al-substituted barium hexaferrite as a function of x. It is seen that H_a grows in proportion to the substitution level.

The specimen number	x	H_a, kOe	M, Gs	$2\Delta H$, kOe	$H_{\rm res}$, kOe
1	1.8	26.9	213.75	1	4
2	1.6	25.8	232.75	0.5	4
3	0.85	19.9	300	0.22	5.28
4	0.4	18.0	337.5	0.135	3.83
5	0	17.4	375	0.09	5.4

Conclusions

The results of the experimental measurements show that the substitution level x strongly influences the value of H_a. As x grows from 0 to 1.8, H_a increases by almost 10 kOe. Thus, by means of the increase in x, it is feasible to obtain Al-substituted barium hexaferrites with the increased field of the crystalline anisotropy and with reduced values of the saturation magnetization. The increase in H_a together with the possibility of changing its value slowly allow the fabrication of doped barium hexaferrite materials with the predetermined parameters, which makes these materials very promising for the advancement towards higher frequencies. At present, the authors continue carrying out the more detailed investigations associated with the results described above.

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ФЕРОМАГНІТНИЙ РЕЗОНАНС В АЛЮМОЗАМІЩЕНИХ ПЛІВКАХ ГЕКСАФЕРИТУ БАРІЮ

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Р е з ю м е

Наведено результати експериментальних досліджень феромагнітного резонансу (ФМР) алюмозаміщених епітаксіальних плівок гексафериту барію $BaFe_{12-x}Al_xO_{19}$, вирощених на підкладці з гексагалату стронцію, x змінювався від 0 до 1,8. Дослідження проводили хвилеводним методом з вимірювальними лініями Р1-32 і Р1-33. В ході експерименту було визначено такі магнітні параметри: поле кристалографічної анізотропії H_a, ширину лінії ФМР $2\Delta H$, резонансне поле $H_{рез}$. Показано, що ступінь заміщення x суттєво впливає на магнітні параметри плівок. Величину анізотропії збільшено майже на 10 кЕ у порівнянні з незаміщеними епітаксіальними плівками гексафериту барію. Проведено порівняння магнітних параметрів чистих та заміщених епітаксіальних плівок гексафериту барію.