The influence of the thickness of films with ferrite nanoparticles on the characteristics of adjustable microwave composite filters

Fedorchuk O.P., Plutenko T.O., V'yunov O.I.
V.I. Vernadsky Institute of General and Inorganic Chemistry of the NAS of Ukraine
E-mail: alex1377c9@gmail.com

INTRODUCTION

Modern communications rely on many types of materials. Among them dielectric materials are used in capacitors, waveguides, and other components of communication systems to store and manage electrical charges without conducting current. Such their nature ensures low energy losses in components and lines based on dielectrics [1].

In contemporary developments of communication technologies, considerable attention is directed toward smart components that exhibit adaptive behavior in response to specific external stimuli. Of particular interest are smart materials capable of dynamically altering their properties in the presence of external factors. Among such materials, ferrites stand out as a noteworthy class of microwave materials. These magnetic dielectrics exhibit the ability to modify their spectral characteristics when subjected to a constant external magnetic field [2]. Ferrites find essential applications as fundamental constituents of non-reciprocal communication components, including filters, circulators, and phase shifters. Nonetheless, it is worth noting that the utilization of ferrites in these applications is associated with substantial energy losses, which sets them apart from non-magnetic dielectrics in terms of performance.

In the present study, we embarked on developing two-component microwave elements, incorporating a dielectric material, $BaTi_4O_{12}$, in combination with a composite material based on photopolymer and nickel ferrite, $NiFe_2O_4$. The main objective of this research was to explore the impact of the composite layer's thickness on the spectral control capabilities of the resulting components. By investigating this aspect, we aimed to enhance the efficiency and effectiveness of the newly created communication elements.

METHODOLOGY

Magnetically adjustable microwave elements consisted of a bulk non-magnetic dielectric cylinder with a high Q-factor, and a composite film containing nano-sized particles of nickel ferrite, were manufactured. The non-magnetic component utilized in the filters was $BaTi_4O_9$, while the composite layer consisted of a photopolymer matrix with introduced ferrite particles.

The nano-sized nickel ferrite particles $NiFe_2O_4$ were synthesized by the citrate sol-gel method. As the initial reagents were used aqueous solutions of $Ni(NO_3)_3$, $Fe(NO_3)_3$, ammonia (25%) and citric acid.

Particles were characterized using X-ray diffraction (XRD) and transmission electron microscopy (TEM). To fabricate the filters, the ferrite particles were mixed with Permabond UV-630 photopolymer and applied to the ends of the dielectric cylinders. The composite films were then exposed to ultraviolet light for curing. We manufactured filters with various film thicknesses, namely 50, 70, 100, and 200 nm. The resulting structures were examined using an Agilent N5230A PNA-L network analyzer to obtain their transmission spectra (Fig. 1).

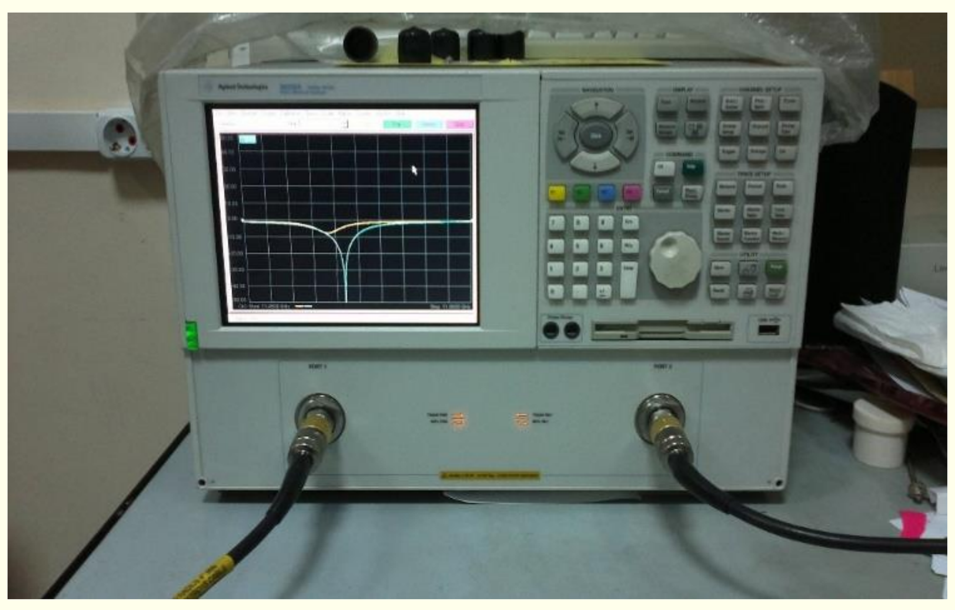

Fig. 1

RESULTS AND DISCUSSION

The XRD patterns revealed the formation of single-phase spinel structures after heat treatment at T = 1173 K with an average particle diameter of 85 nm. Curves 1-4 show XRD patterns at the temperatures of 873, 973, 1073 and 1173 K respectively.

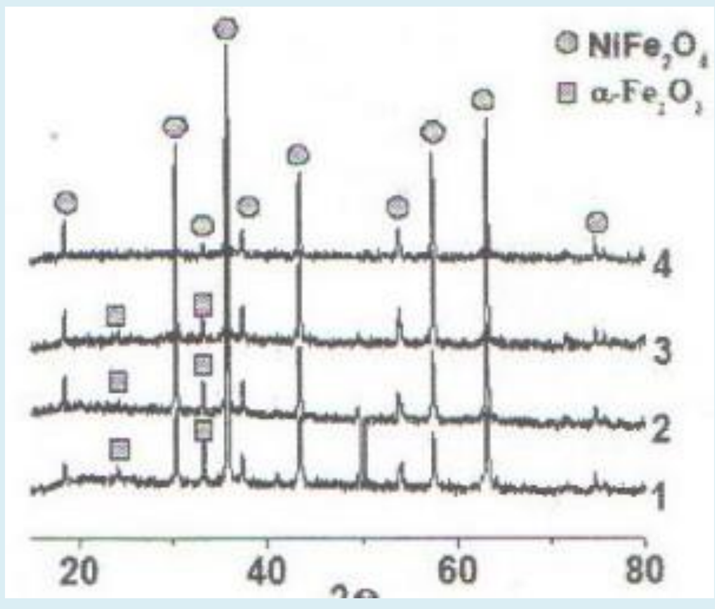

Fig. 2.

On the Fig. 3 the spectra of microwave elements with a ferrite film of 50, 70, 100 and 200 μm are presented.

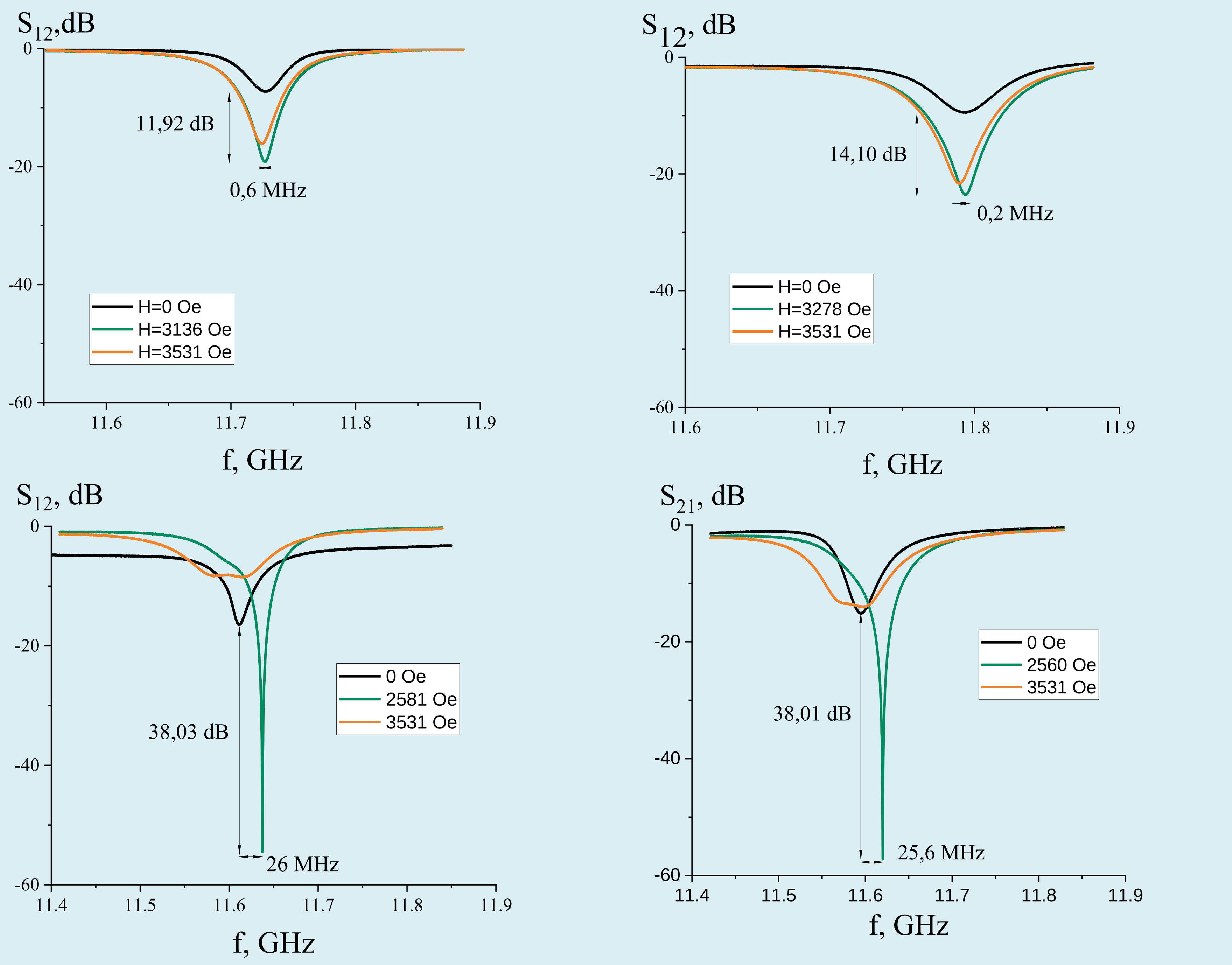

Fig. 3.

In line with classical electrodynamics, we anticipated that the frequency shift would be directly proportional to the volume fraction of the ferrite component. Indeed, the frequency shift of the filters increased with the thickness of the ferrite film, ranging from 0.6 MHz for a 50 nm film to 26 MHz for a 100 nm film. However, further investigation is required to understand why increasing the film thickness to 200 nm did not significantly affect the frequency shift. This particular aspect warrants thorough examination.

Interestingly, despite the relatively small volume of the ferrite films, we observed steep field-driven peaks in the spectra of the filters. The external magnetic field played a crucial role in modifying the resonance frequency and peak absorption of the filters.

The described heteromaterial filters can be used as a new smart adjustable component base for classical ferrite devices (filters, circulators, generators, etc.).

References:
[1] Microwave dielectric materials in the BaO–TiO_2 system. In *Dielectric Materials for Wireless Communication, Sebastian, M. T., Ed. Elsevier: 2008; pp 49-82*.
[2] Salih, S. J.; Mahmood, W. M., Review on magnetic spinel ferrite (MFe_2O_4) nanoparticles: From synthesis to application. *Heliyon* ***2023, 9 (6), e16601***.