OBSERVATION OF A DOUBLET FERROMAGNETIC RESONANCE IN CUBIC AND HEXAGONAL FERRITES AT MILLIMETER WAVELENGTHS*

Mohammed Nurul Afsar and Hua Chi

Department of Electrical Engineering
Tufts University
Medford, Massachusetts 02155 - 5528

ABSTRACT

Ferromagnetic resonance from two individual magnetic sublattices of ferrimagnetic materials has been observed for the first time in the laboratory. Separate g-factor (gyromagnetic ratio) values were then measured from the resonance experiment. A high signal to noise ratio millimeter wave broad band Fourier transform spectrometer and a high intensity field (140,000 gauss) d.c. magnet were utilized for this measurement.

INTRODUCTION

Ferrimagnetic resonance in ferrites, magnetoplumbites and rare-earth iron garnets has never been studied at frequencies above the microwave. It requires an unique combination of very high intensity field d.c. magnet and extra sensitive broad band spectrometer at millimeter wavelength region. We have utilized the newly constructed large aperture optical dispersive Fourier transform spectrometer capable of providing a continuous spectrum thorough out the frequency range 60 GHz to 1000 GHz together with the 4 inch warm bore 140,000 gauss "Bitter" solenoid d.c. magnet. We have seen the ferromagnetic resonance from the two individual magnetic sublattices of ferrimagnetic materials. We have measured the separate g-factors.

Although ferrimagnetic resonance has always been treated theoretically as a doublet (or multiplet) resonance [1] , it has never been observed as such in the laboratory. Our high resolution, high signal to noise ratio dispersive Fourier transform spectrometer resolved the doublet after a sufficiently high intensity magnetic field has been applied to split the doublet. Figure 1 shows the "induced" ferromagnetic resonance splitting into a doublet for a cubic type ferrite paint (gray absorber) at an applied magnetic field intensity of 113,000 gauss. Clearly the nearly identical g-factors require ultra-high fields to be measured separately. The measurement of separate g-factors in a variety of ferrite materials will be of great importance to many ferrite specialists. We are not observing a zero-field splitting because our doublet is not resolved at zero magnetic field intensity; indeed, at 75,300 gauss magnetic field intensity, the doublet is not yet resolved in the gray specimen (see Figure 2). We have shown this gray specimen to contain cubic ferrites. No resonance can be seen in the absence of an applied magnetic field. The ferromagnetic resonance appears, when the magnetic field is turned on, and moves to a higher frequency as the field is increased. We have also observed a similar splitting effect for a composite material prepared with iron carbonale spheres at similar applied magnetic field intensity.

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* This research program is supported by the U. S. Army, Contract Number MDA908-88-R-0210

FERROMAGNETIC RESONANCE

Our recent work [2} showed that induced ferromagnetic can be observed at many millimeter wave frequencies when an external high intensity d.c. magnetic field was applied, for both cubic and hexagonal ferrite powder suspended in a thin layer of paint or poly-crystalline disc according to the rule $f_{resonance} = \gamma H$, where $f_{resonance}$ is the resonance frequency, γ is the gyromagnetic ratio and H is the magnetic field intensity.

The gyromagnetic ratio γ is related to the Lande g factor via the equation $\gamma = ge/2mc$, where e is the absolute value of the electronic charge, m is the mass of the electron, c is the velocity of light. The g factor is approximately equal to 2 and for a g factor of 2, the gyromagnetic ratio γ becomes approximately equal to 2.8 MHz. Therefore a resonance at 300 GHz (one mm in wavelength) requires a magnetic field intensity of 100, 000 gauss compared to 10,000 gauss required at K-band.

HEXAGONAL FERRITES

In our earlier work [2], we have observed a strong natural ferromagnetic resonance at 240 GHz in the absence of an applied magnetic field in a black paint (see Figure 3). This black paint appeared to be a rare- earth iron garnet. The natural ferromagnetic resonance at 240 GHz also appears in the presence of an applied magnetic field(as can be seen in Figure 3 around 240 GHz). We now term this natural ferromagnetic resonance as an exchange resonance. A recent chemical analysis on this type of specimens supported our comments. Polycrystalline magnetoplumbites are magnetically uniaxial. The hexagonal crystal structure of polycrystalline magnetoplumbites gives rise to a spontaneous internal magnetization which can be observed as a zero-field ferromagnetic resonance. Again, the unique combination of high fields and a high resolution high signal to noise ratio millimeter wave spectrometer would be required for all but a few formulations. Although the application of an external magnetic field would not be expected to influence the exchange resonance that we have seen in the rare earth garnet, a sufficiently intense external field will "tune" the resonance of a polycrystalline magnetoplumbite.

In Figure 3 the induced ferromagnetic resonance obediently appears at lower frequencies (near 85 GHz) at an applied magnetic field intensity of 28,370 gauss. It appears as a doublet. This doublet moves to higher frequencies as the external d.c. magnetic field intensity is increased according to the rule $f = \gamma H$. At an applied magnetic field intensity of about 70,000 gauss this doublet in the rare-earth garnet specimen completely separates into two sharp isolated resonance lines.

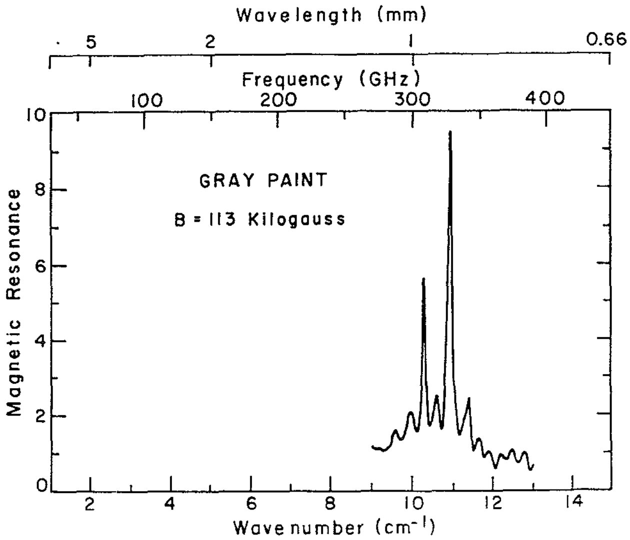

Figure 1. A doublet ferromagnetic resonance appears at very high intensity magnetic field values. The single induced ferromagnetic resonance splits into a doublet for this cubic type ferrite paint (gray absorber) at magnetic field intensity greater than 80,000 Gauss. This effect appears for all cubic ferrites.

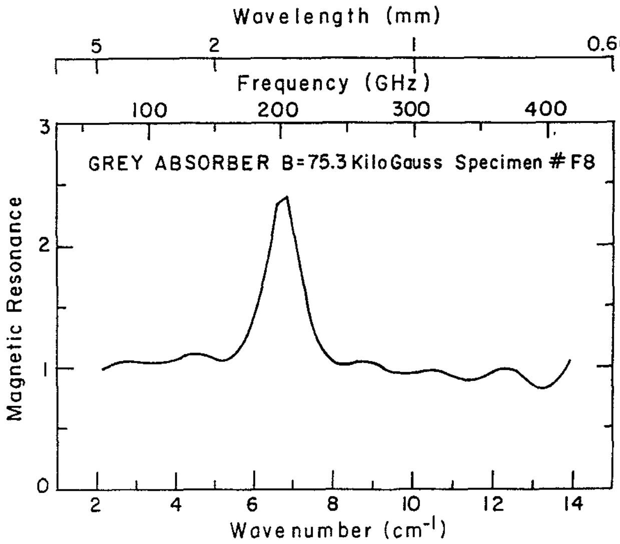

Figure 2. The doublet is not resolved at an applied magnetic field intensity value of 75,300 Gauss. This unresolved single induced ferromagnetic resonance moves to higher frequencies with increasing magnetic field intensity according to the rule $f_{resonance} = \gamma H$, where γ is the gyromagnetic ratio and H is the magnetic field intensity.

INSTRUMENTATION

We have now two dedicated millimeter wave broad band dispersive Fourier transform spectrometer for this measurement program. In a dispersive Fourier transform interferometric configuration, the specimen rests in one active arms of the two beam interferometer thereby provides phase information in addition to amplitude information. These lead us to acquire data of complex dielectric permittivity and complex magnetic permeability as a continuous function of frequency in the millimeter and submillimeter wavelength region. In one of the interferometric configuration, the specimen arm passes through a four inch bore of a 140,000 gauss Bitter solenoid d.c. magnet. The accessibility of the magnet bore reduces the optical beam diameter to 60 mm. Therefore this interferometer is only suitable for measurement in the frequency region 60 - 450 GHz in the magnetic field. We have constructed another interferometer, with 100 mm diameter optics together with a 110,000 gauss superconducting magnet. We expect the new spectrometer to operate in the frequency region 35 - 450 GHz.

ACKNOWLEDGEMENT

We are indebted to our colleague and friend Dr. Kenneth J. Button for his advice and suggestions. We would also like to acknowledge the use of high magnetic field facility at the MIT Francis Bitter National Magnet Laboratory.

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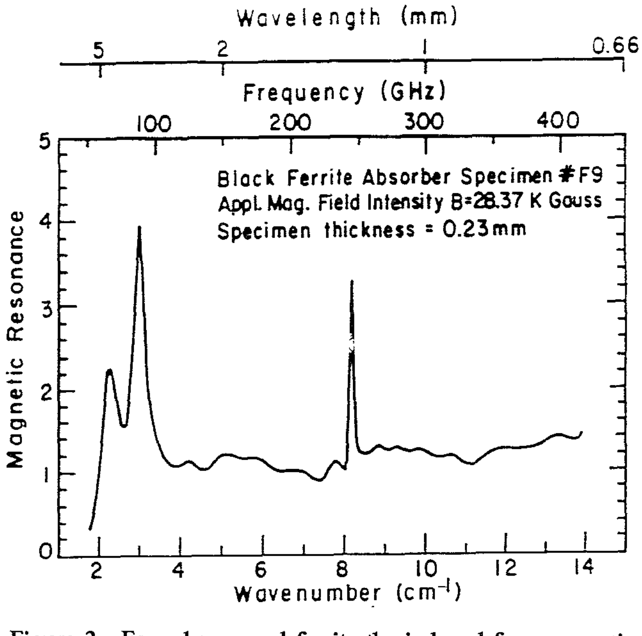

Figure 3. For a hexagonal ferrite the induced ferromagnetic resonance appears as a doublet at a much lower applied magnetic field intensity (near 85 GHz for for an applied magnetic field intensity value of 28,370 Gauss) value. This doublet moves to higher frequencies as the external d.c. magnetic field intensity is increased to higher values. The sharp single resonance line at 240 GHz is the strong natural ferromagnetic resonance. The natural ferromagnetic resonance is the exchange resonance and independent of the applied external d.c magnetic field intensity.