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Magnetostriction and substrate effect on microwave permeability of metal films

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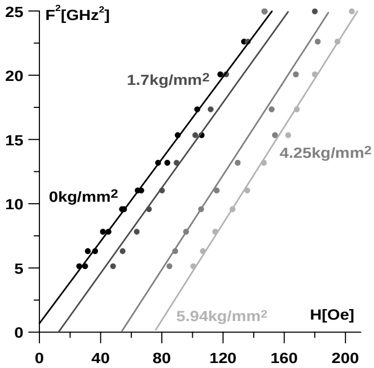
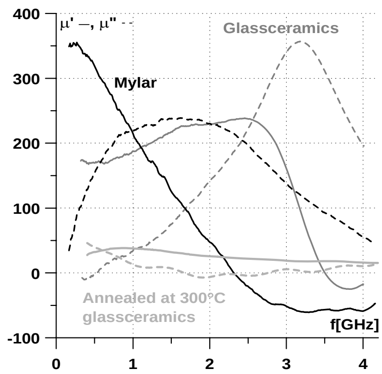
Abstract –The strip-line field-domain technique is applied to measure ferromagnetic resonance spectra of metal films magnetron-sputtered on polymer and ceramic substrates at the frequency range of 0.13-12GHz. The spectra of samples on polymer substrates are measured under varying stretching load. The contribution of magnetostriction to anisotropy field is determined and the effects of stretching on quasistatic permeability and resonance frequency are calculated. The observed difference in permeability of samples on flexible and rigid substrates arises because of different mechanical strain in metal film. A 300°C annealing effectively removes the strain, therefore decreasing the resonance frequency even below that of the samples on flexible substrates.

Material permeable at microwaves is needed for a lot of applications including radar absorbers, mobile antennas, RFID sensors, etc. For some time ferrites satisfied the engineering needs, but miniaturization and frequency increase revealed the problem: the magnetization M_S of ferrites is 3-5 times lower than that of ferro-alloys, therefore according to Snoek's law [1], or in case of thin films or flakes to Acher's law [2] the product of quasistatic permeability μ_0 and the cutoff frequency F of ferrites is much lower than that of metals [3]. A metal film must be thin enough to suppress the effect of eddy currents that mask the microwave permeability μ. Because of the flexibility and heat-expansion factor differences of a substrate and metal the sputtered film is usually under high mechanical tension σ. This tension is related through magnetostriction to the anisotropy field H_A and consequently to μ_0 and to the resonance (cutoff) frequency F. Qualitatively the effect has been observed in coaxial measurements of wound films on flexible substrates [4]. Our aim is to determine the effect of mechanical tension of metal film on parameters F and μ_0 of its magnetic spectrum.

The samples under study are 0.05-0.5μm thick Fe-based films magnetron-sputtered on Mylar and glassceramic substrates. Magnetic spectra are measured in a strip cell [5] within the range of 0.13-12GHz under external bias $H_{bias}\leq$1000Oe parallel to the wave vector. The flexibility coefficients of Mylar and metal film are determined with a tensile-testing machine. The transversal magnetostriction coefficient is determined by FMR measurements of a sample under stretching load up to 6kg/mm^2. The measured magnetostriction contribution to anisotropy field H_A is about $\partial H_A/\partial\sigma\approx$-2.5Oe$\times$mm$^2\times$kg^{-1}, with this data we calculate the effect of mechanical tension on $\partial\mu_0/\partial\sigma$ and $\partial F/\partial\sigma$. The magnetostriction coefficient of Fe-based film $\partial l/(\lambda\times\partial H_{bias})\approx$ -2.5$\times$10^{-5}Oe^{-1} is determined assuming that bias and stretching cause the same shift of F (Fig.1).

The difference in magnetic spectra of films sputtered on flexible and rigid (glassceramics) substrates (Fig.2) arises because the thermal-expansion coefficients of iron and substrates differ significantly, but the strain in metal on flexible substrates is obviously lower. As the sputtered metal is quenched, 300°C annealing removes the strain even on rigid substrates, as a result F falls below the setup operating range [5]. Therefore the proper selection of substrate flexibility, thermal-expansion and annealing or quenching of sputtered samples is a way to control the microwave magnetic properties of thin films. The measurements of FMR spectra under external bias reveal a correlation between the substrate flexibility and H_A of a film and explain the effect of annealing on μ at microwaves.





Left figure: The effect of stretching tension (the data correspond to strain in metal) on the FMR frequency of 0.12μm-thick iron film on 12μm-thick Mylar substrate.

Right figure: The effect of substrate flexibility and annealing (300°C 1hr) on magnetic spectra of iron-based films

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