Magnetoelastic interactions and magnetic damping in $Co_2Fe_{0.4}Mn_{0.6}Si$ and $Co_2FeGa_{0.5}Ge_{0.5}$ Heusler alloys thin films

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$Co_2Fe_{0.4}Mn_{0.6}Si$ (CFMS) and $Co_2FeGa_{0.5}Ge_{0.5}$ (CFGG) Heusler alloys are among the most promising thin film materials for spintronic devices due to a high spin polarization, low magnetic damping and giant/tunneling magnetoresistance ratios. Despite numerous investigations of Heusler alloys magnetic properties performed up to now, magnetoelastic effects in these materials remain not fully understood; due to quite rare studies of correlations between magnetoelastic and other magnetic properties, such as magnetic dissipation or magnetic anisotropy. In this research we have investigated epitaxial CFMS and CFGG Heusler alloys thin films of thickness in the range of 15-50 nm. We have determined the magnetoelastic tensor components and magnetic damping parameters as a function of the magnetic layer thickness. Magnetic damping measurements revealed the existence of non-Gilbert dissipation related contributions, including two-magnon scattering and spin pumping phenomena. Magnetoelastic constant B_{11} values and effective magnetic damping parameter α_{eff} values were found to be in the range of $-(6\text{-}30)\times 10^6$ erg/cm³ and $1\text{-}12\times 10^{-3}$, respectively. The values of saturation magnetostriction λ_S for CFMS Heusler alloy thin films were also obtained. The correlation between α_{eff} and B_{11}, depending on magnetic layer thickness was observed based on the performed investigations of magnetic properties.

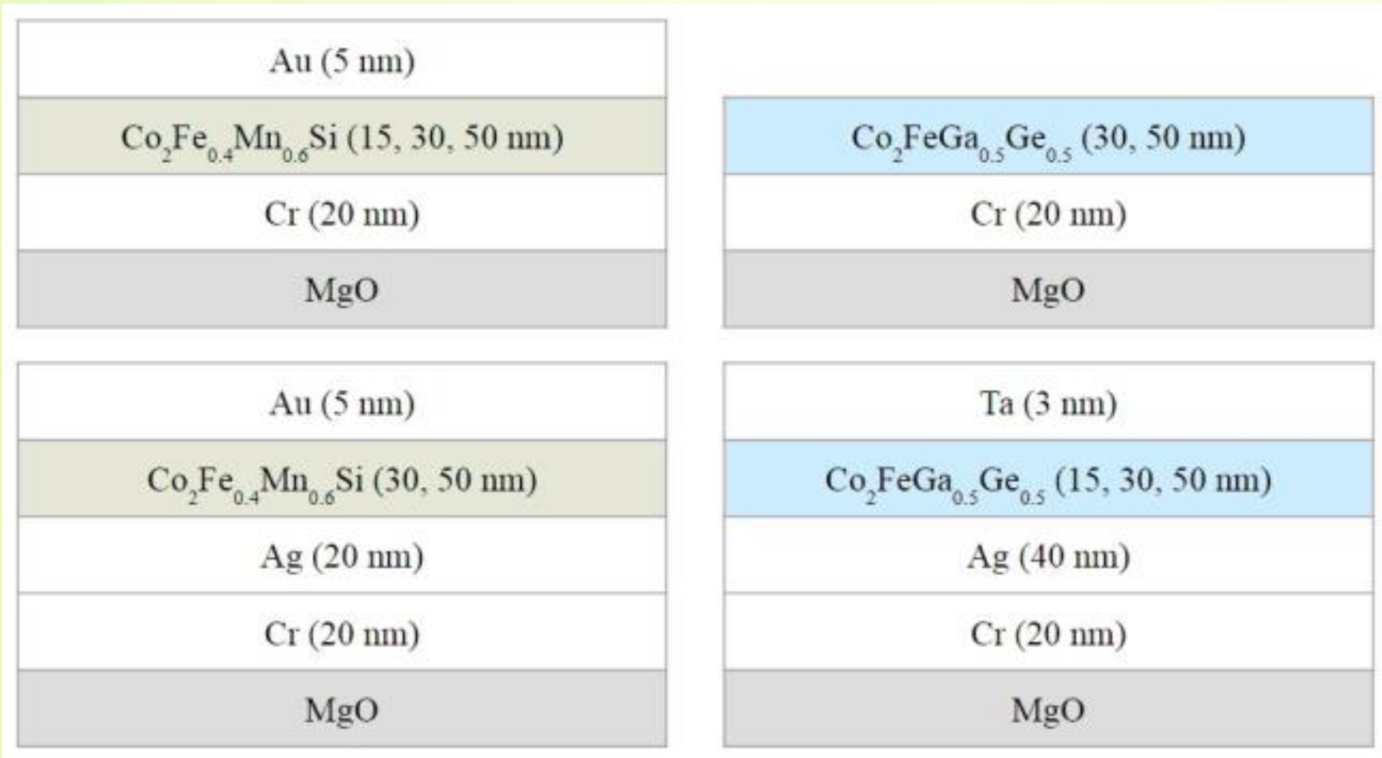

Figure 1. Investigated samples belong to 4 series: CFMS and CFGG on Cr buffer layer with or without the additional Ag buffer layer.

We obtained lattice unit parameters: $a_{\perp} = 5.675 \pm 0.001$ Å and $a_{\parallel} = 5.643 \pm 0.005$ Å indicating a tetragonal deformation (Fig. 3), which results in the appearance of the strain induced anisotropy.

Taking the data from our experiments: $\varepsilon_{11} = -2.44\times 10^{-3}$, $B_{11} = -17.50\times 10^6$ and elastic constants, we have obtained the value of the strain induced anisotropy constant $K_{SI} = (1.39 \pm 0.23)\times 10^5$ erg/cm³. It has the opposite sign and a small value in comparison to the overall magnetocrystalline anisotropy of relatively low and negative value $|K| < 1.5\times 10^6$ erg/cm³ which was determined from FMR/SQUID studies. Strain causes an increase of the anisotropy constant and reduces its absolute value. The minimal tetragonal distortion value, which is necessary to switch the magnetic layer anisotropy from an easy-plane to an easy axis type, was estimated to be at least $\varepsilon_{11\text{-}min} \approx -0.07$; but such a large strain is not likely to be obtained.

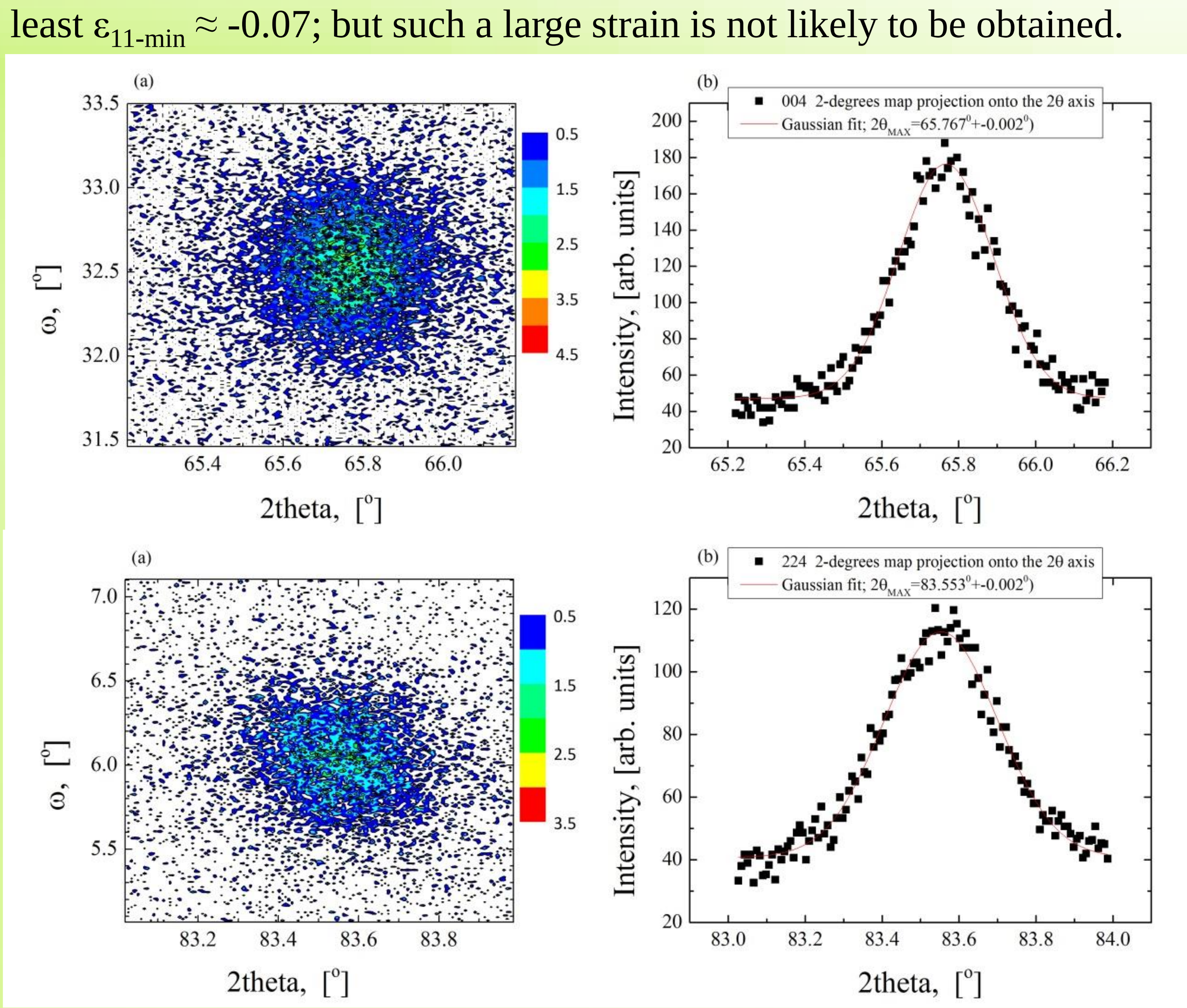

Figure 3. The X-ray intensity distribution around the (004) (up) and (224) (down) reflection (**a**) and note projection into the 2θ axis (**b**) for the 50-nm-thick CFMS layer grown on the Ag buffer.

For all investigated series of samples the magnetoelastic constant absolute values decrease with decreasing magnetic layer thickness (see Fig. 2). Hence, the magnetoelastic effect in such thin layers is weaker than that expected in bulk materials, the absolute values of extrapolated $B_{11,V}$ magnetoelastic constant are bigger than the absolute values of B_{11} magnetoelastic constant of the investigated thin films. The saturation magnetostriction value $\lambda_S = 1.44 \times 10^{-5}$ corresponding to $B_{11,V}$(CFMS) value, is in accordance to the experimental value reported for $Co_2Cr_{0.6}Fe_{0.4}Al$ Heusler alloy bulk sample[93] and the recent theoretical calculations for Co_2XAl Heusler alloys, where X = V, Ti, Cr, Mn, Fe.

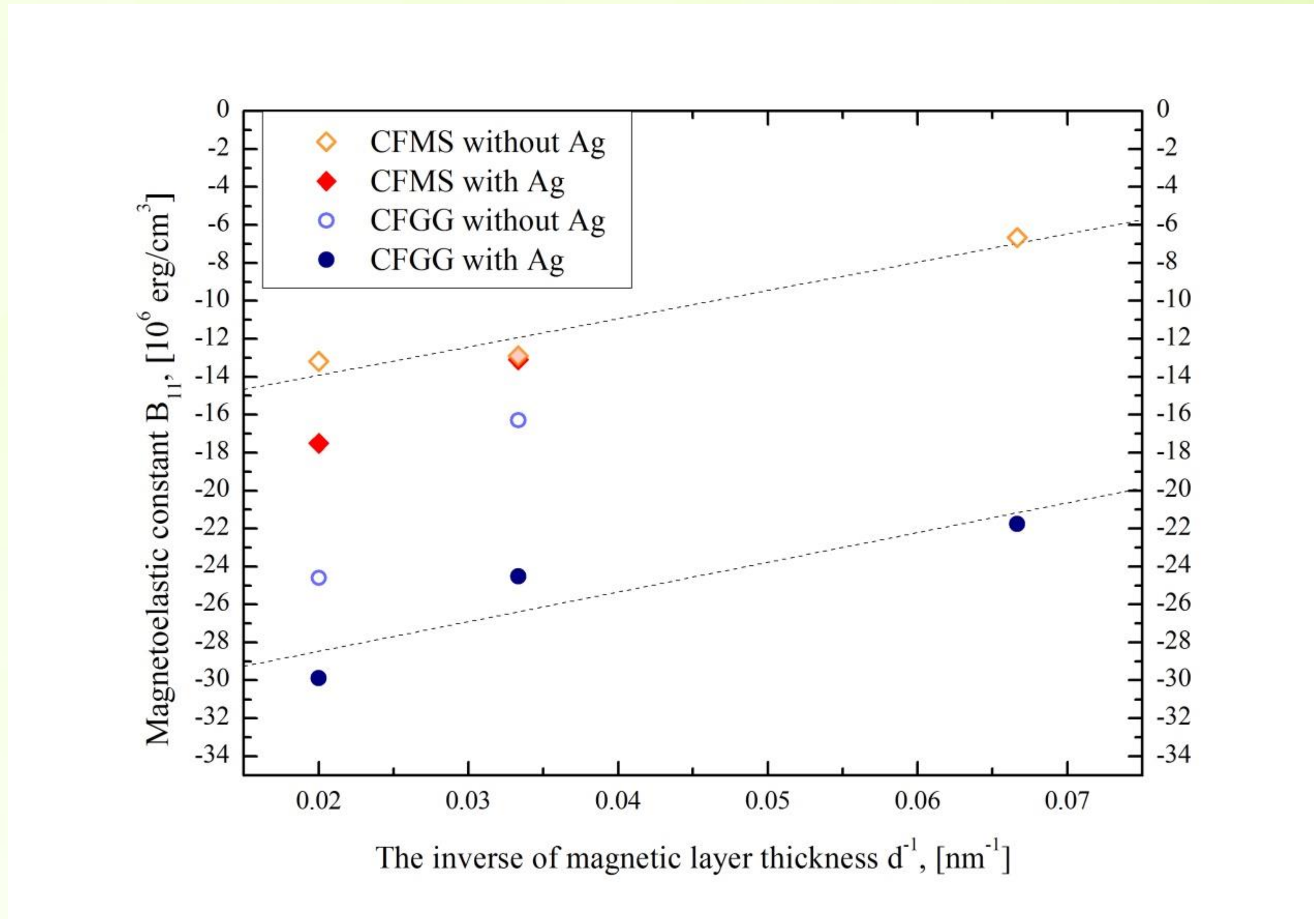

Figure 2. Magnetoelastic constant B_{11} for CFMS and CFGG films as a function of the inverse of magnetic layer thickness at room temperature.

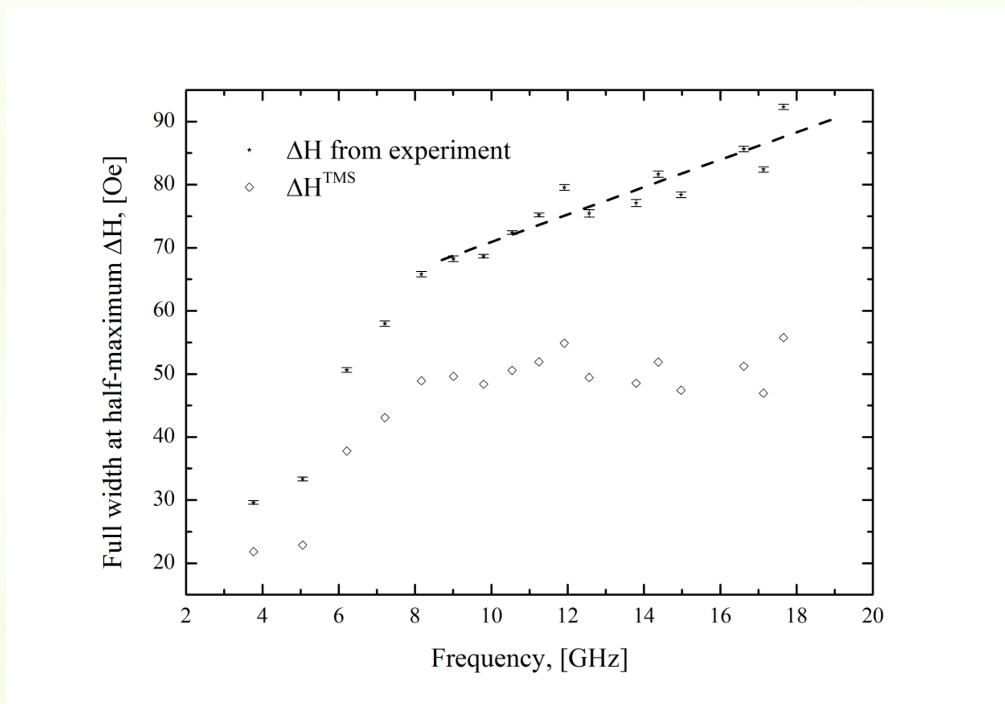

Figure 4. Example of the resonance line FWHM as a function of frequency at room temperature.

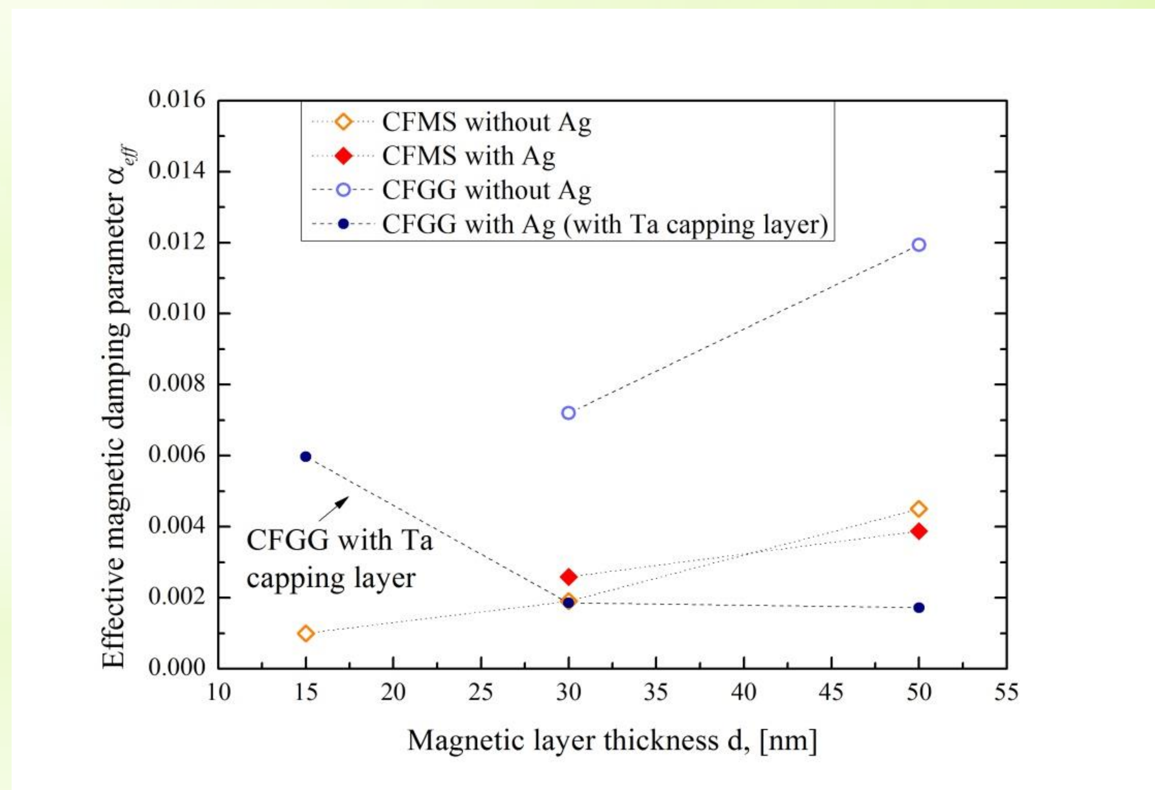

Figure 5. Effective magnetic damping parameter α_{eff} as a function of magnetic layer thickness at room temperature.

In the low frequency range the ΔH^{TMS} vs. frequency is nonlinear, while it saturates at high frequencies (Fig. 4). For this reason in the high frequency range, the slope of the ΔH can be assumed to be proportional to effective magnetic damping parameter α_{eff}.

It was found that the effective magnetic damping parameter α_{eff} increases with the magnetic layer thickness (Fig. 5).

It should be emphasized that for all studied samples, the increase of magnetic layer thickness is accompanied by the increase of the magnetoelastic constant B_{11} absolute value. Therefore, for the samples, where effective magnetic damping parameter α_{eff} may be considered as Gilbert damping parameter α (without spin pumping contribution due to a presence of Ta), the increase of the absolute value of magnetoelastic constant is accompanied by the increase of the damping parameter (see also Fig.6).

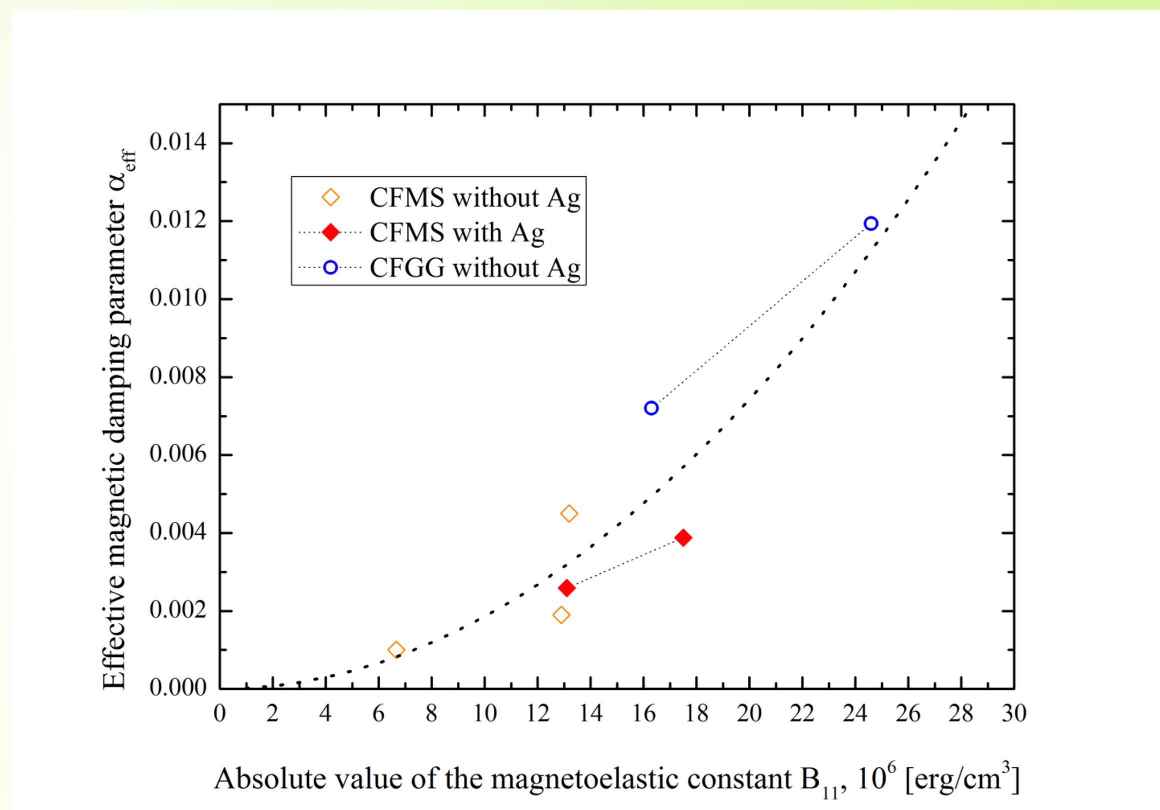

Figure 6. The correlation between the absolute values of the magnetoelastic constants B_{11}, and the effective magnetic damping parameter a_{eff}

Conclusions

- Magnetoelastic properties and magnetic damping for several series of quaternary $Co_2Fe_{0.4}Mn_{0.6}Si$ and $Co_2FeGa_{0.5}Ge_{0.5}$ Heusler alloy thin magnetic films were determined by the Strain Modulated FMR and the Vector Network Analyzer FMR methods, respectively. The magnetoelastic constants were found to have relatively small and negative values while saturation magnetostriction for all the studied samples was positive. It was shown that two-magnon scattering and spin pumping phenomena play an important role in the magnetic damping of microwaves in the studied magnetic thin films.
- The saturation magnetostriction ($\lambda \approx 10^{-5}$) and low magnetic damping parameter ($\alpha_{eff} \approx 10^{-3}$) values in the investigated Heusler alloy thin films are similar to the results of the pioneering work[73], where a new class of materials promising for spin-mechanical devices was found. Calculated strain, which is necessary to switch the magnetic anisotropy from the easy-plane to the magnetization easy axis type, is too large ($\varepsilon_{11\text{-}min} \approx -0.07$) to be achieved in the epitaxially grown magnetic layers.
- In the samples for which it was possible to neglect the spin pumping phenomenon (i.e. without the Ta cover layer), the correlation between the Gilbert damping parameter and magnetoelastic constants was obtained. Based on the fact that both the magnetic damping parameter and the absolute value of the magnetoelastic constant increase with magnetic layer thickness, it was concluded that the enhanced magnetoelastic effects are accompanied by a stronger magnetic damping. An increase of the absolute values of magnetoelastic constants with increasing thickness of the magnetic layer can be explained as a result of surface magnetoelastic coupling and/or the thickness dependent structural ordering. An increase of Gilbert damping can be correlated with increasing magnetoelastic constants or changes in the band structure caused by the changes of structural ordering.

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