Optimizing soft magnetic properties in FeGa/NiFe/Al_2O_3 multilayers for magnetoelectric applications

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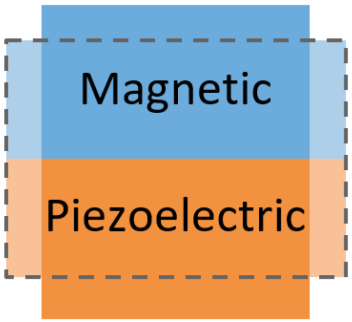
Motivation: Strain-mediated magnetoelectric (ME) devices

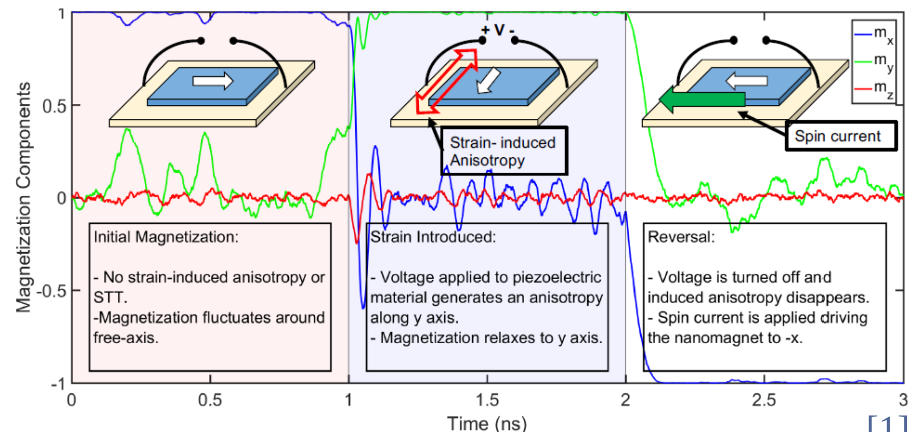
Strain mediated ME composite



Magnetoelastic materials with small gilbert damping and high magneto-mechanical coupling can enhance speed and efficiency for ME spintronic + antenna devices

Strain-assisted magnetization reversal w/ spin transfer torque

- Higher efficiency than STT alone
- Faster switching
- Small gilbert damping is desired

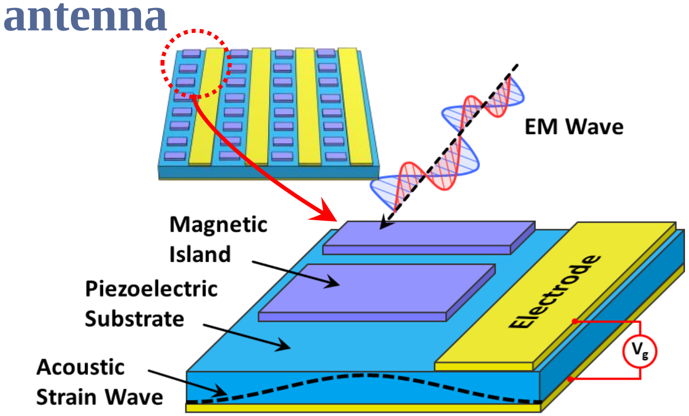


[1]

Shear-wave ME microwave antenna

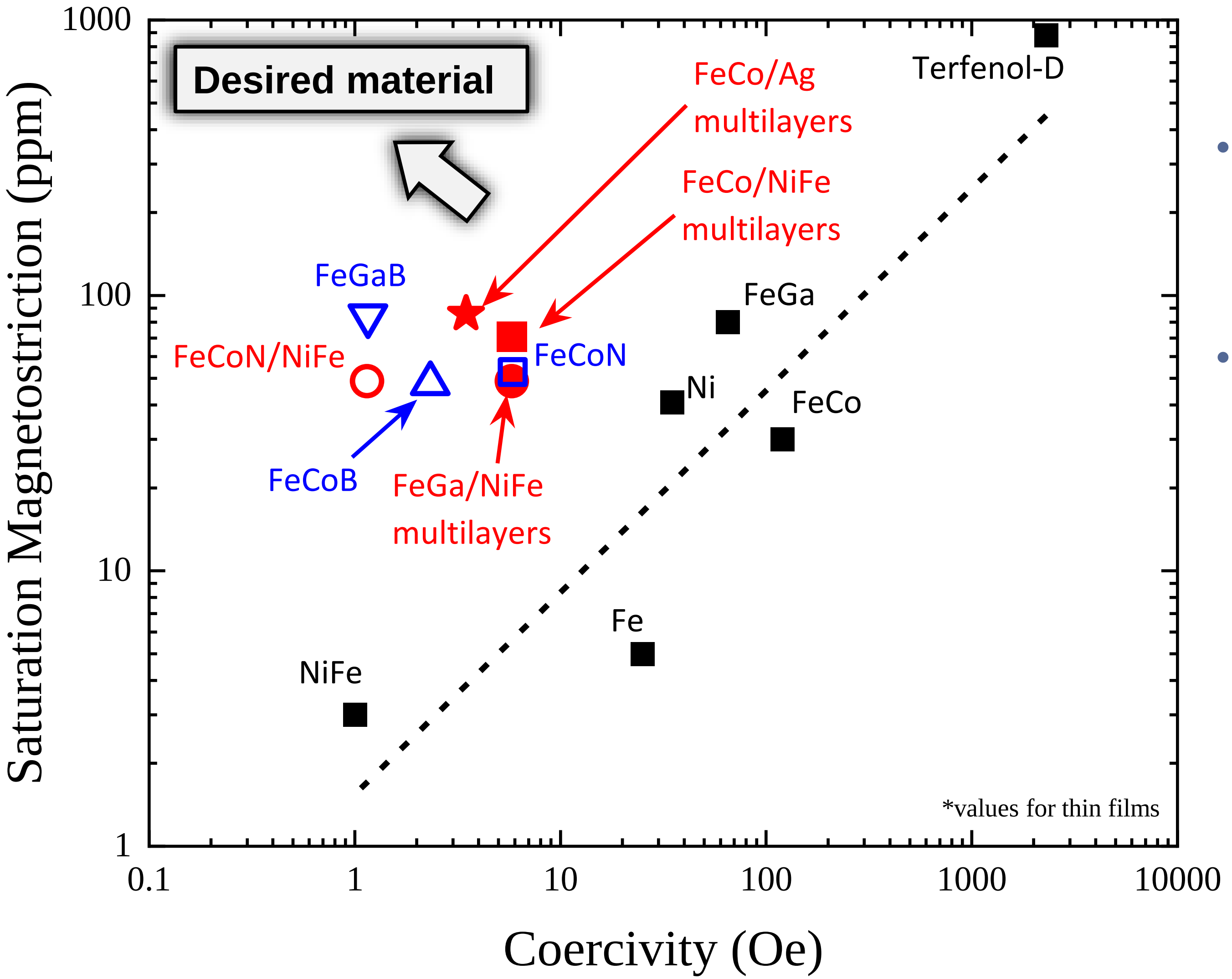
$$\lambda_{AW} = \frac{v_{substrate}}{f_{EM}} \approx 10^{-5}\,\lambda_{EM}$$

- Higher efficiency at electrically small antenna sizes



[1] Kani, Nickvash, John T. Heron, and Azad Naeemi. "Strain-mediated magnetization reversal through spin-transfer torque." *IEEE Transactions on Magnetics* 53.11 (2017): 1-8.

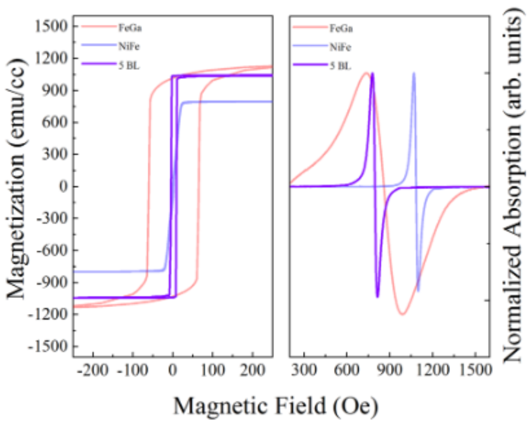
Material space of magneto-elastic thin films



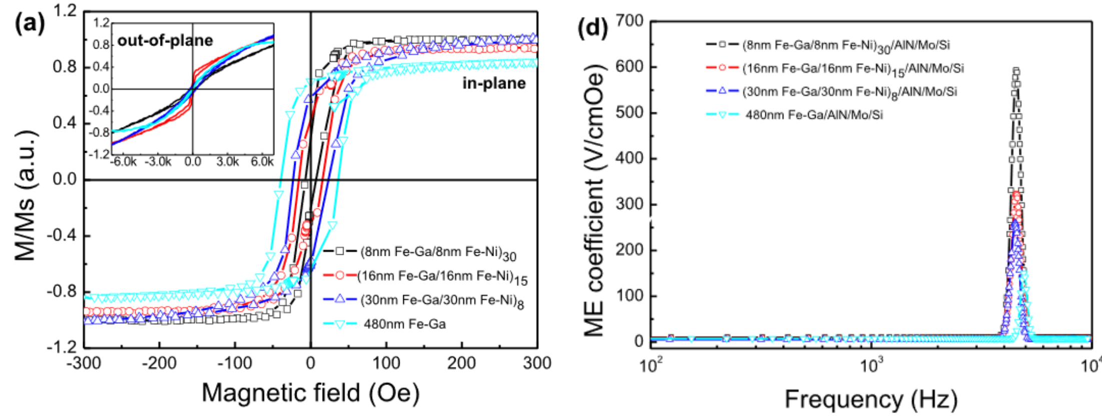
- Typically, a trade-off magnetic softness & magnetostriction
- Achieving desired material properties requires engineering of magnetic film nano/microstructure

Prior studies on FeGa/NiFe multilayers

1:1 FeGa/NiFe bilayers [1]



1:1 FeGa/NiFe on AlN (ME device)[2]



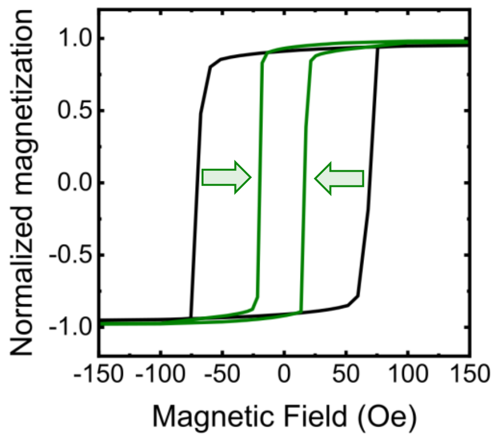
- Prior studies found that multilayering of FeGa with NiFe can enhance soft magnetic properties (reduce coercivity) and increase magneto-mechanical coupling

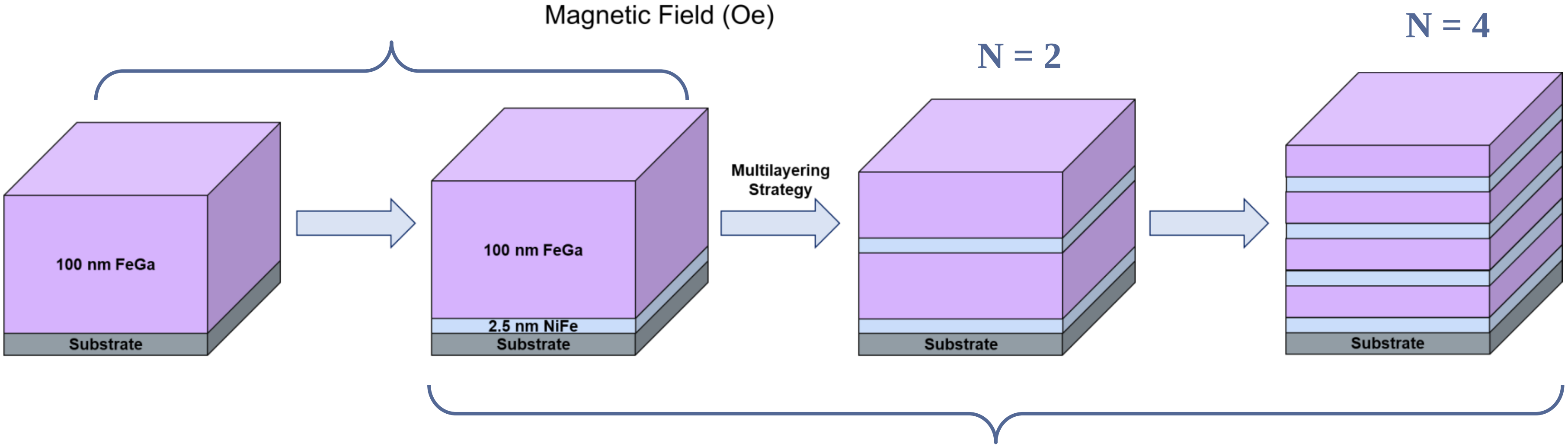
- Origins of enhancement not properly understood in prior studies

[1] Rementer, Colin R., et al. "Tuning static and dynamic properties of FeGa/NiFe heterostructures." *Applied Physics Letters* 110.24 (2017): 242403.
[2] Shi, Jiaxing, et al. "A study of high piezomagnetic (Fe-Ga/Fe-Ni) multilayers for magnetoelectric device." *Journal of Alloys and Compounds* 806 (2019): 1465-1468.

Multilayering strategy in this work

We previously found that the underlayer effect of NiFe promotes soft magnetic properties in FeGa thin films by influencing microstructure[1]



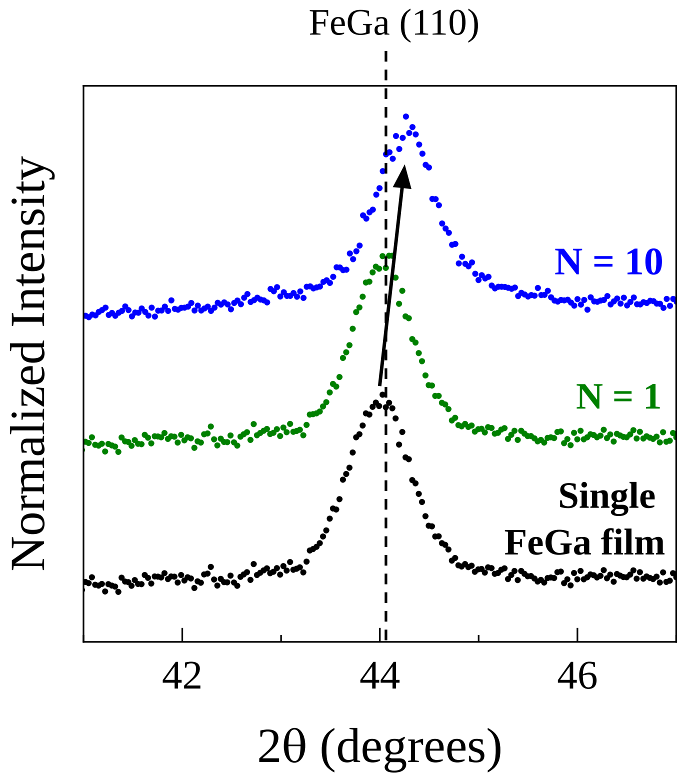


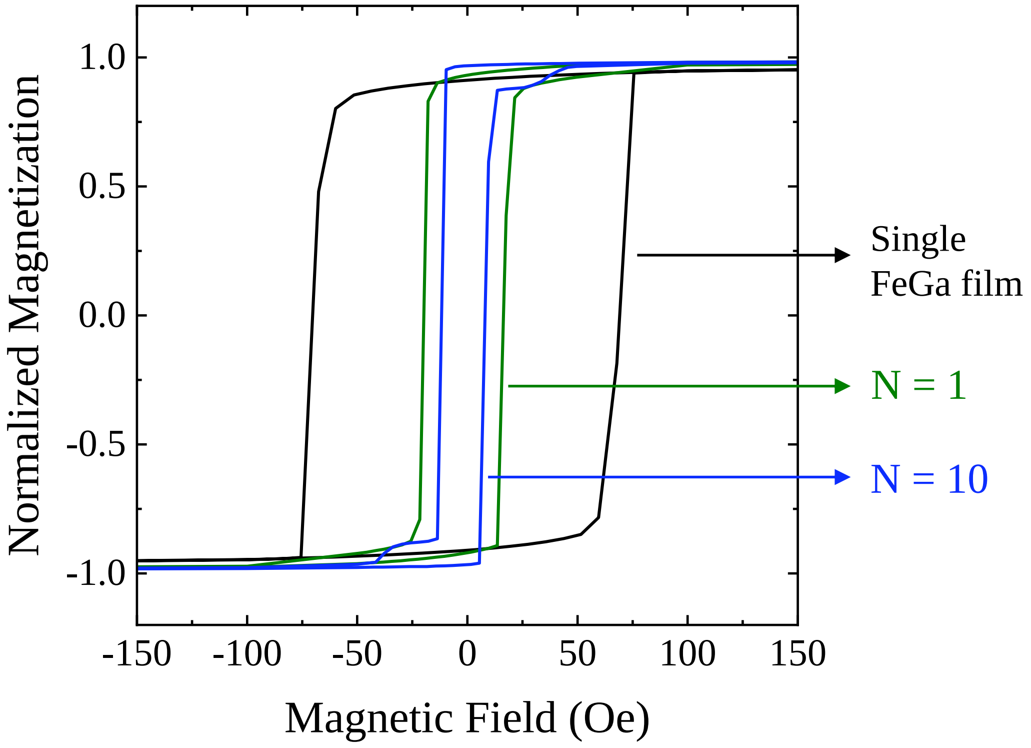
Multilayering strategy to optimize soft magnetic properties

- Total FeGa film thickness kept constant (100 nm) and NiFe interlayer thickness kept constant (2.5 nm) with increasing # of FeGa/NiFe bilayers

[1] Acosta, A., Fitzell, K., Schneider, J.D., Dong, C., Yao, Z., Sheil, R., Wang, Y.E., Carman, G.P., Sun, N.X. and Chang, J.P., 2020. Underlayer effect on the soft magnetic, high frequency, and magnetostrictive properties of FeGa thin films. *Journal of Applied Physics*, *128*(1), p.013903.

XRD and MH loops of sputtered FeGa/NiFe films



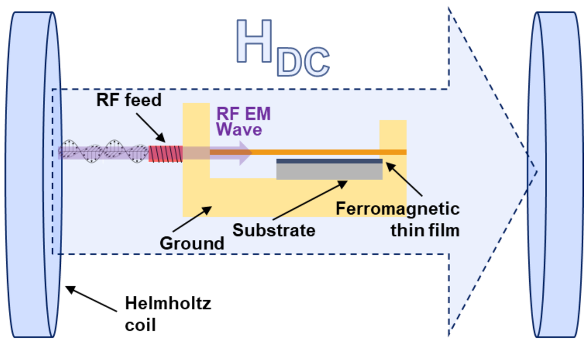


- Multilayer stack has ~0.7% increase in compressive film strain

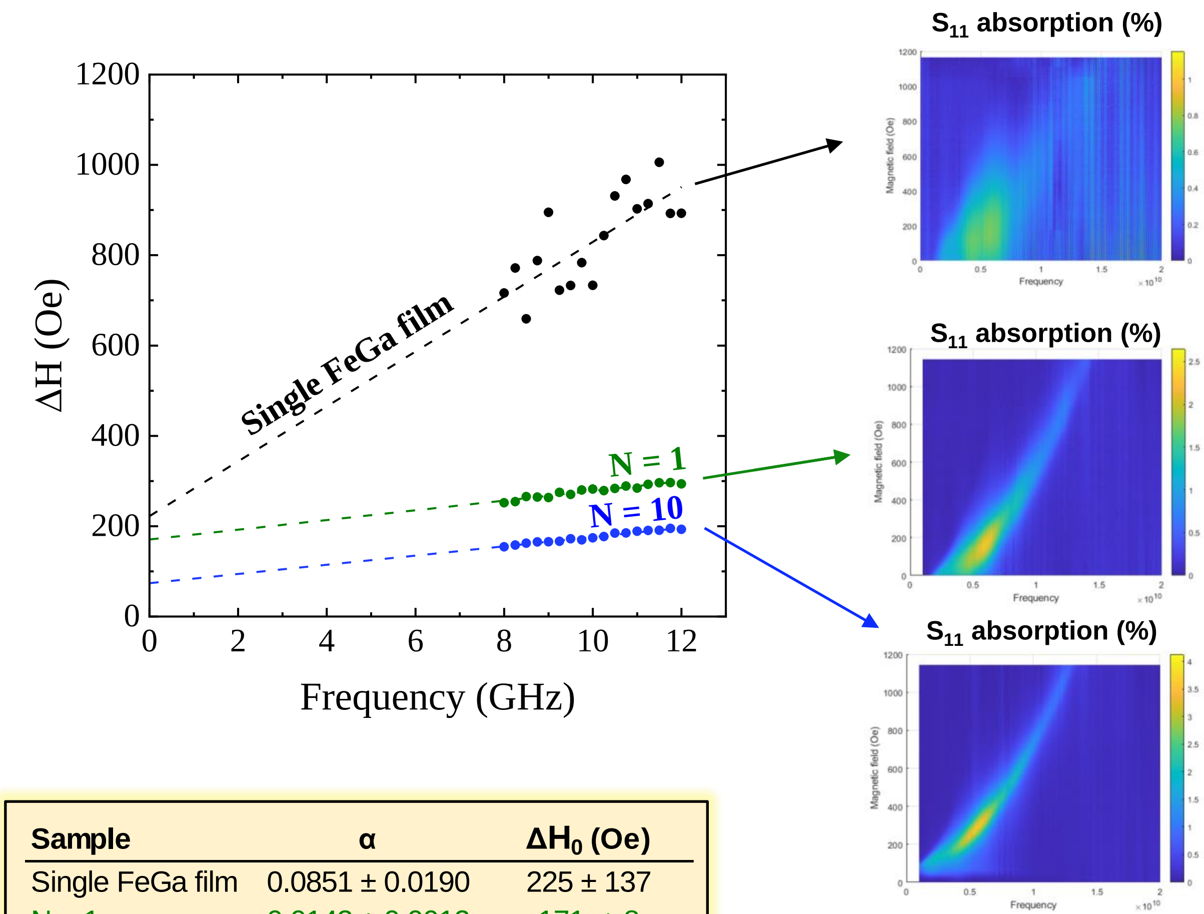
- 10 bilayer structure (N =10) has a coercivity of 10 Oe
- This is a further enhancement beyond underlayer effect in a single FeGa/NiFe bilayer structure (N=1)

Ferromagnetic resonance for FeGa/NiFe multilayers

FMR set-up



$$\mu_0 \Delta H = \mu_0 \Delta H_0 + \frac{4\pi\alpha f_{FMR}}{\gamma}$$

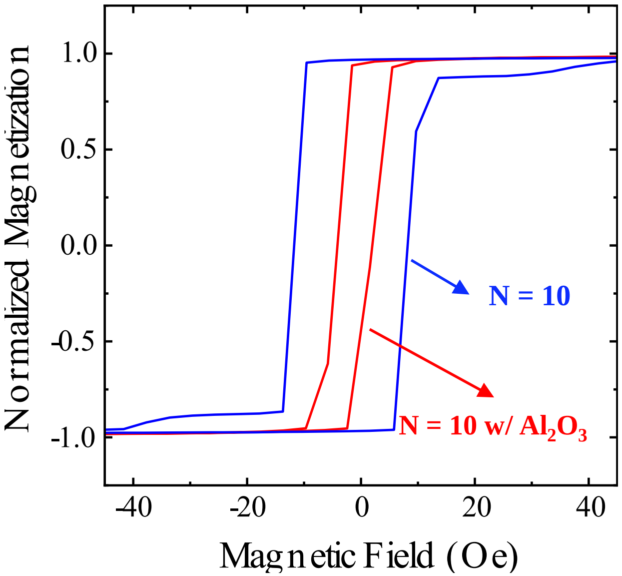


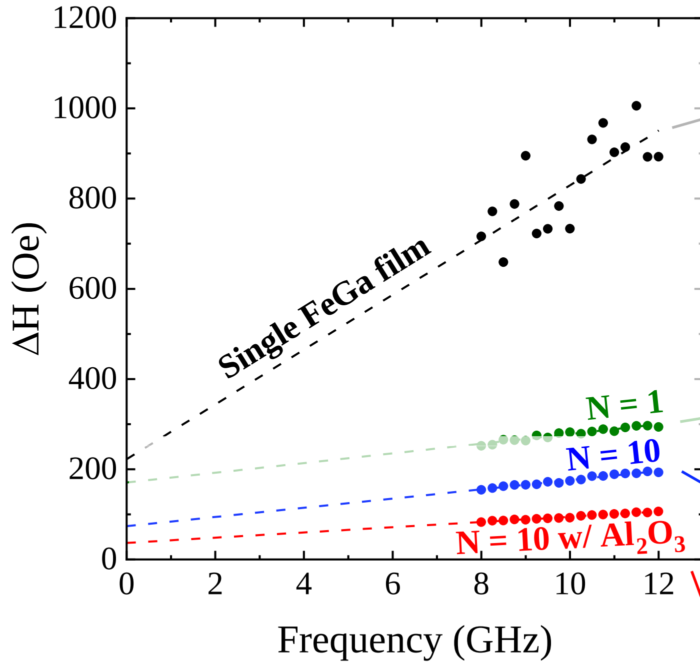
- N = 10 multilayer has a comparable gilbert damping but lower inhomogeneous linewidth than N = 1 bilayer
- Improvement is attributed to microstructural homogeneity with additional NiFe interlayers

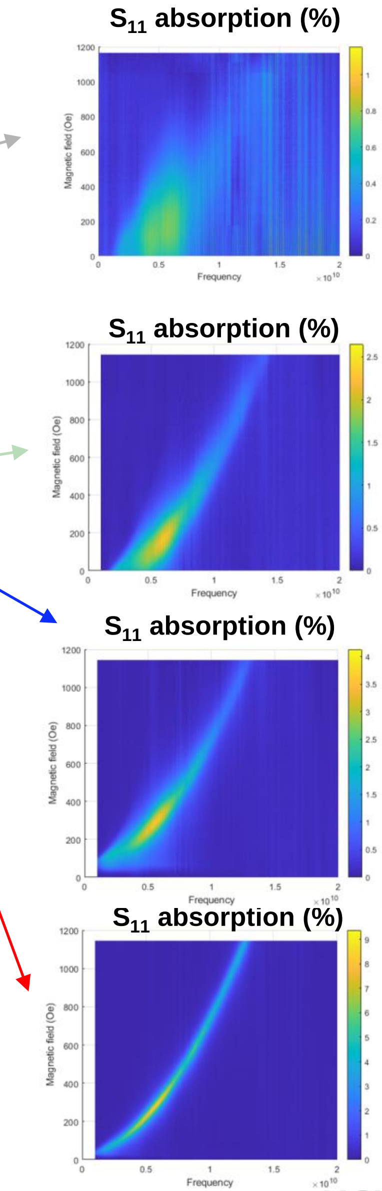
Sample	α	ΔH_0 (Oe)
Single FeGa film	0.0851 ± 0.0190	225 ± 137
N = 1	0.0143 ± 0.0012	171 ± 8
N = 10	0.0143 ± 0.0006	73 ± 4

error reported to ± 1 σ

Effect of Al_2O_3 insulating interlayer in FeGa/NiFe multilayers

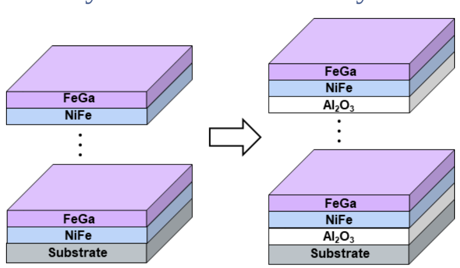






Design strategy:

- 2.5 nm Al_2O_3 insulating layer to reduce eddy current losses
- Al_2O_3 layer deposited *after* FeGa and *before* NiFe layer to preserve NiFe underlayer effect on FeGa layers

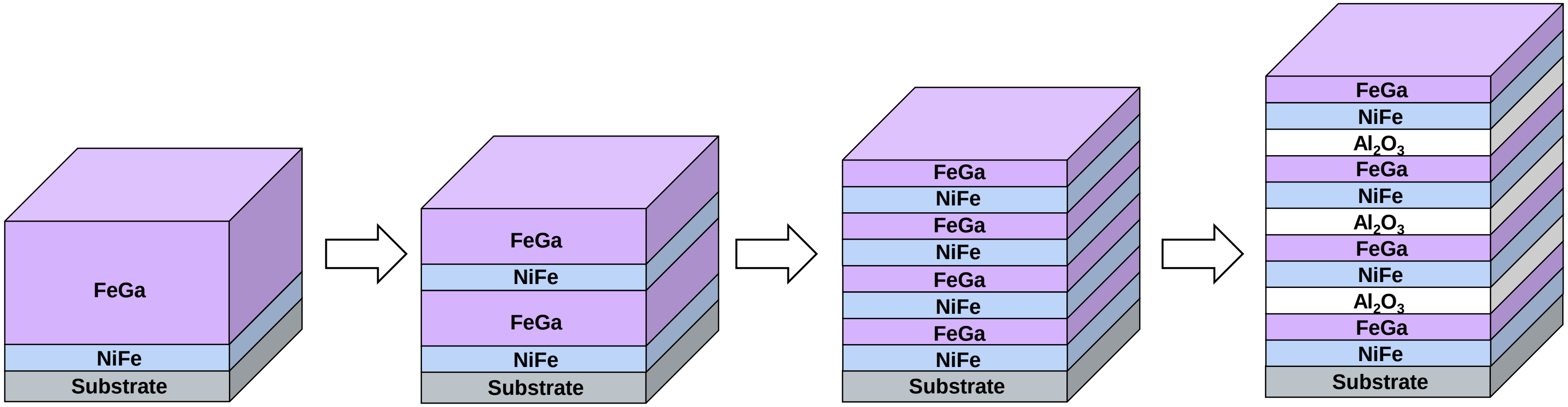


Sample	α	ΔH_0 (Oe)
Single FeGa film	0.0851 ± 0.0190	225 ± 137
N = 1	0.0143 ± 0.0012	171 ± 8
N = 10	0.0143 ± 0.0006	73 ± 4
N = 10 w/ Al_2O_3	0.0081 ± 0.0003	38 ± 2

error reported to ± 1 σ

Summary & conclusions

- We previously found that a thin underlayer influences microstructure of FeGa thin films to improve soft magnetic properties (coercivity decrease from 85 Oe to 15 Oe)
- Using NiFe and Al_2O_3 as interlayers can be exploited to further reduce coercivity (~3 Oe) and achieve a low gilbert damping coefficient and a small inhomogeneous linewidth ($\alpha = 0.008$, $\Delta H_0 = 73$ Oe)



- FeGa/NiFe/Al_2O_3 multilayering is a promising strategy for both enhanced efficiency and switching speed for strain-mediated ME spintronic & microwave antenna devices

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TANMS

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