
# High Frequency permeability of electroplated CoNiFe and CoNiFe-C alloys

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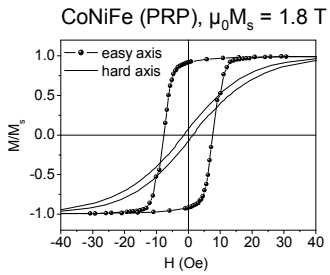
## Summary

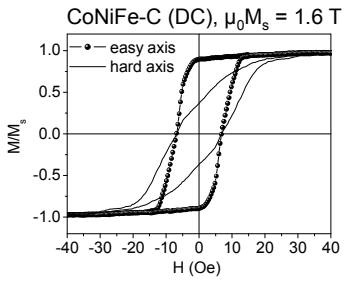
•CoNiFe and CoNiFe-C electrodeposited by pulse reverse plating (PRP) and direct current (DC) techniques
•We observe that magnetic losses in these alloys can be described in terms of classical Eddy current and anomalous losses associated with ferromagnetic resonance (FMR) absorption.
•A crossover from Eddy current to anomalous losses is found in CoNiFe, whereas CoNiFe-C shows only anomalous losses.

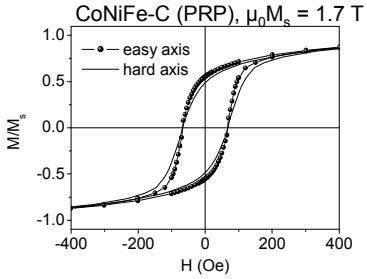
## Experiment

•CoNiFe and CoNiFeC were electrodeposited from aqueous solutions.
•Galvanic pulse reverse plating and DC plating were carried out using an averaged current density of 16 mA $cm^{-2}$. The pulse reverse plating waveform has a duty cycle of 90 % and ratio of reverse/forward current amplitude pulse of 4.
•Plating was carried out in open atmosphere with strong mechanical stirring.
• Films were electrodeposited from fresh solutions on Si substrate with sputtered Cu seed layer cut into 5 x 5 $mm^2$.

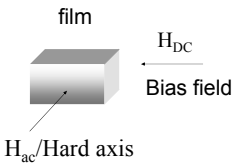
## Results and Discussion

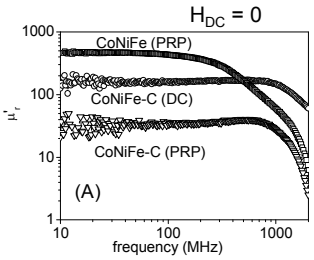


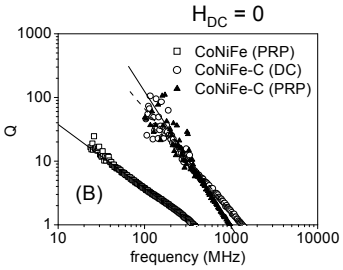



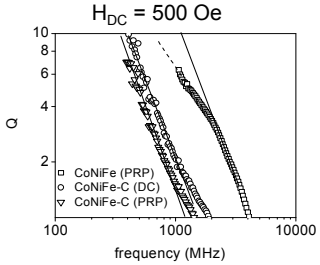




### High Frequency Permeability and Quality factor ($Q = \mu_r'/\mu_r''$)




| | $\mu_0$Ms(T) | $H_{ch}$ (Oe) | ρ(μΩ cm) | μr @100MHz | F(MHz) @ Q=10 |
|---|---|---|---|---|---|
| CoNiFe(PRP) | 1.8 | 1.2 | 24 | 450 | 30 |
| CoNiFe-C(DC) | 1.6 | 7.0 | 85 | 165 | 320 |
| CoNiFe-C(PRP) | 1.7 | 69 | 38 | 35 | 320 |

•The permeability CoNiFe(PRP) remains almost constant $\mu_r'$ ~ 450 up to 30 MHz with a quality factor (Q) larger than 10.
•DC and PRP plated CoNiFe-C, show permeability of $\mu_r'$ = 165 and $\mu_r'$ = 35 with Q > 10 up to 320 MHz, respectively
•Anomalous Losses in DC and PRP plated CoNiFe-C are associated with a Gaussian distribution of ferromagnetic resonance frequency.

•The incorporation of C to CoNiFe reduces Eddy current losses and increases quality factor.

## Conclusions

•Distinct signatures of Eddy current and anomalous loss are observed in CoNiFe(PRP).
•A crossover between Eddy current and anamalous loss is also observed CoNiFe(PRP).
•Reversal permeability of CoNiFe (PRP) was found to remain constant at 450 up 30 MHz with a quality factor (Q) larger than 10. The resistivity of CoNiFe is 24 μΩ cm and the main magnetic loss at high frequency with zero bias is associated with Eddy current.
•DC and PRP electroplated CoNiFe-C showed higher resistivity of 85 μΩ cm and 38 μΩ cm, lower permeability and higher quality factor, which is only reduced to unity at frequencies as high as 1 GHz due to anomalous losses.
•The operating frequency of CoNiFe and CoNiFe-C are limited by Eddy current and anomalous losses, respectively.

**ACKNOWLEDGMENTS**

**This project was funded by Enterprise Ireland under the program ILRP/05/PEIG/02B**