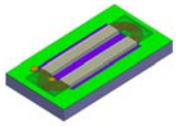
Electrodeposited multilayer amorphous alloy suitable for high frequency integrated inductors

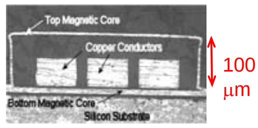
Paul McCloskey[a], Brice Jamieson[a], Terence O'Donnell[a], Donald Gardner[b], Michael A. Morris[c], Saibal Roy[a]
Tyndall National Institute, Lee Maltings, Prospect Row, Cork.
[b]Intel Corporation, Santa Clara
[c] Chemistry Department, University College Cork, College Road, Cork..

Background

Integration of On-chip Inductors

- On-chip inductors are a major challenge in the move towards monolithic solutions [1].
- A magnetic core in such devices => smaller footprint and less EMI issues [2]
- High switching frequencies => lower values of inductance and capacitance





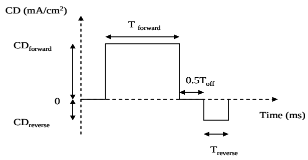
Magnetic material properties required

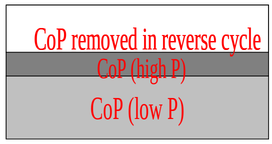
Low losses at high frequency

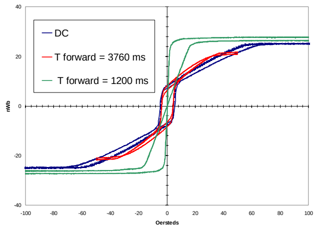
- Co-P alloys have high ρ and low Hc => low eddy current loss and low hysteresis loss.
- DC plated films exhibit perpendicular anisotropy [3]

=> very low μ and high Hc

- For in-plane anisotropy a multi- nano-layer structure of alternating compositions produced by pulse reverse plating [4] or pulse plating at two different current densities [5] is required.
- High P contents used [4], [5]=> relatively low saturation magnetisation say 0.5 to 0.6 T







Temperature stability

- Important because of subsequent processing steps
- Oda et al [6] used small additions of Tungsten (atomic weight =183.8) to improve crystallisation temperature of amorphous FeCoP alloys. However baths containing Tungsten have a tendency to be unstable.
- Rhenium has a high atomic weight 186.2 and can be readily co-deposited with Iron group metals [7].
- The present work is concerned with the characterisation of a novel electrodeposited alloy i.e. CoPRe

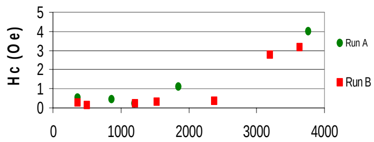
Improved Saturation

Component	Amount
H_3PO_3(g l^{-1})	30
Co CO_3 (g l^{-1})	39.4
$CoCl_2.6H_2O$ (g l^{-1})	181
H_3PO_4 (g l^{-1})	50
Temperature (^oC)	72 +/- 1
Anode	Co (99.5%)
Uniaxial magnetic field	200 Oe

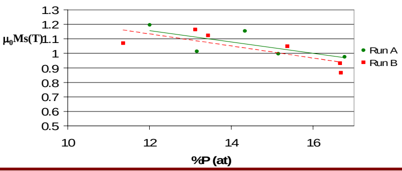
Substrate; silicon wafer with 20 nm Ti and 200 nm Cu seed layer

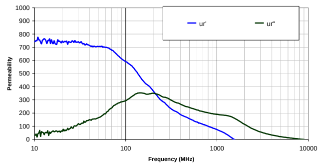
Plating waveform - Pulse reverse plating $T_{forward}$=870 to 3760 ms, $CD_{forward}$=170 mA/cm^2, $T_{reverse}$= 54 ms, $CD_{reverse}$=67 mA/cm^2 T_{off} =72 ms.

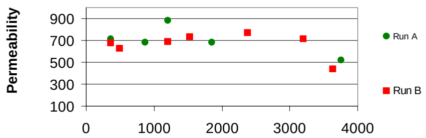
Also investigated effect of pH



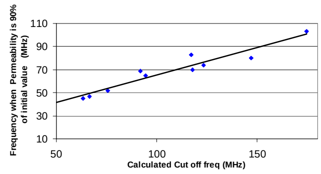
Forward on time, $T_{forward}$ (ms)







Forward on time, $T_{forward}$ (ms)



Fall off frequency,f $_{m = 90\% \text{ of initial value}}$ in the range 47 to 103 MHz

Cut off frequency for eddy current loss may be estimated using;

$f_{cut\ off} = \rho / \pi \mu_r \mu_0 t^2$ where ρ = resistivity , μ_r and μ_0 are the relative and absolute permeabilities and t is the thickness

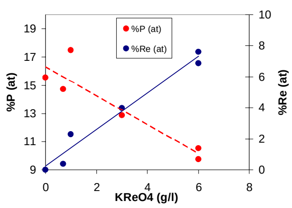
Present study; thickness 1.7 to 2.5 μm and ρ 116 το 136 μOhm cm

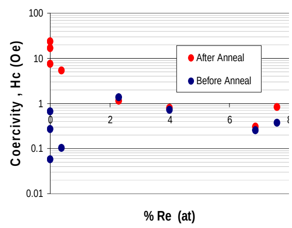
Thermal Stability

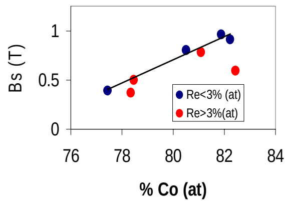
Component	Concentration (g /l)
H_3PO_3	65
Co CO_3	39.4
$CoCl_2.6H_2O$	181
H_3PO_4	50
$KReO_4$	0 to 6

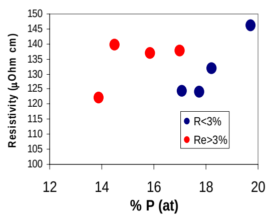
Re has a high atomic weight (186.2)

Also investigated effect of pH









Conclusions

- Optimisation of P content

μ_0Ms in the range of 0.9 to 1.2T, Hc <0.5 Oe,

Permeability of around 700 holding out to a maximum 103 MHz

Resistivity in the range of 116 to 136 μOhm cm,

Hk largely between 12 and 19 Oe (higher values at lower P)

- CoPRe =>Improved Thermal Stability

Co $_{100-x-y}$, P_x , Re_y where; 9.7 at % < x <17.5 at % and 0.4 at % < y < 7.6 at %.

Other properties i.e. saturation magnetization, Ms and resistivity, ρ largely unaffected

References

[1] D. S. Gardner et. al., IEEE International electron device meeting, (IEDM), San Francisco (USA), 11-13 December 2006
[2] S. Roy et. al J. Magn. Mag. Mater, 290-291, 1524 (2005).
[3] J.M. Riveiro et. al, IEEE Trans. Mag., 16, 1426 (1980).
[4] J.M. Riveiro, G. Riveiro, IEEE Trans. Mag., 17, No. 6, 3082 (1981).
[5] L.Perez et al, Sens. Act. A 109 208 (2004)
[6] Oda et al, US Patent 584494A (1996)
[7] A.Brenner, "Electrodeposition of Alloys", Academic Press, London 1963

The authors would like to acknowledge Enterprise Ireland and Intel for their support

www.tyndall.ie