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Magnetic Field Enabled Selective Metallisation of Dielectric Substrates

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ICT Evening Seminar, Harrogate, UK
December 5th 2017

Agenda

- Applications of Selective Metallisation
- Previous research on the effects of a Magnetic Field on Electrochemical Deposition
- Selective Catalysation of a non-conductive substrate by application of a Magnetic Field
  - Concept
  - Synthesis of Magnetic-Catalytic Nanoparticles
  - Characterisation of Magnetic-Catalytic Nanoparticles
  - Selective catalysation and metallisation using Magnetic-Catalytic Nanoparticles
- Conclusions
- Future Work

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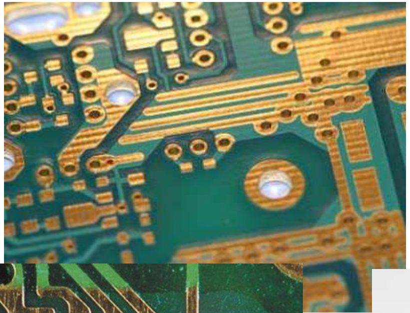
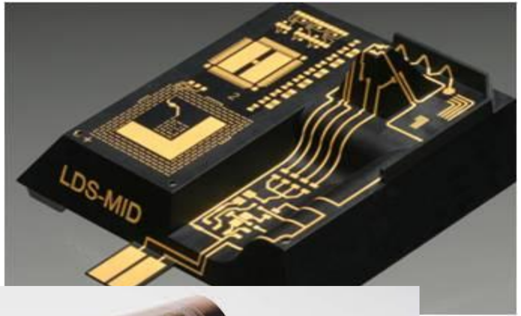
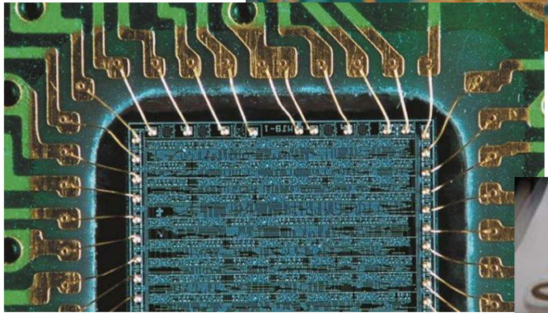
The Importance of Selective Metallisation in the Electronics Sector

- Printed Circuit Boards
- Molded Interconnect Devices
- Micro-electronics
- Printed Electronics
- Wearable Technology
- RFIDs
- ……and many more







Effect of a Magnetic Field in Electrodeposition

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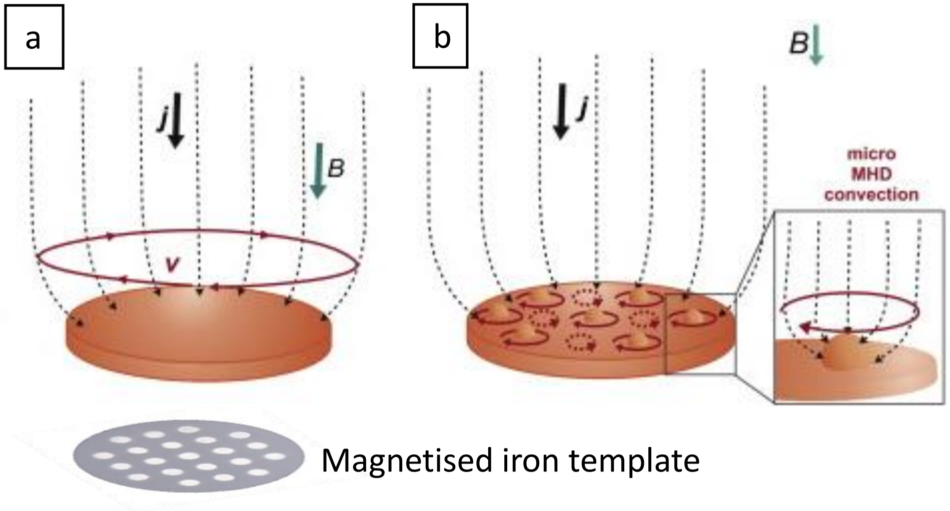
Electromagnetic interactions

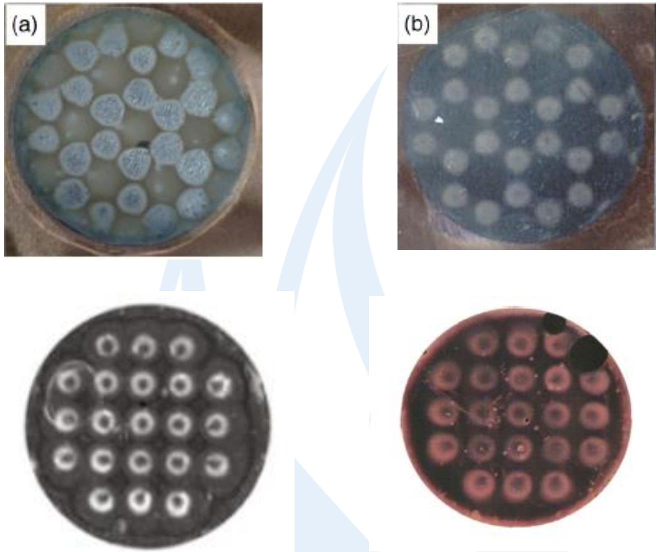
Magnetic fields induce the magnetohydrodynamic effect (MHD – effect)

Gradient magnetic fields induce a micro-MHD effect:



Schematic representation of a - MHD effect, b – micro-MHD effect.

L.M.A. Monzon, J.M.D. Coey, , Electrochemistry Communications, 42 (2014) 38–41



[1]] P. Dunne, J.M.D. Coey, Phys. Rev. B - Condens. Matter Mater. Phys. 85 (2012) 1–21.
[2] M. Uhlemann, K. Tschulik, A. Gebert, G. Mutschke, J Frohlich, A. Bund, X. Yang, K. Eckert, et al Eur. Phys. J. Spec. Top., 220 (2013) 287-302
[3] K. Tschulik, R. Sueptitz, J. Koza, M. Uhlemann, G. Mutschke, T. Weier, A. Gebert, L. Schultz, Electrochimica Acta, 56(1) (2010) 297-304

Effect of a Magnetic Field in Electrodeposition

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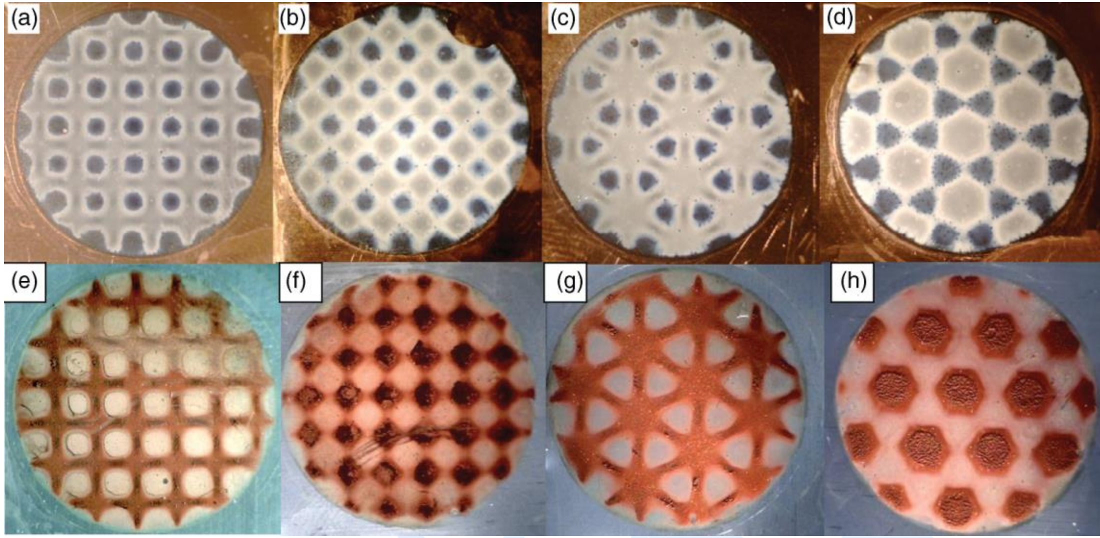
Electrodeposition in a magnetic field has been shown to effect:

- Layer roughness
- Morphology
- Layer density
- Layer thickness
- Crystal structure
- Corrosion resistance

……and can also enable some metal patterning

However the substrate must be ***conductive***



PHYSICAL REVIEW B **85**, 224411 (2012)

Patterning metallic electrodeposits with magnet arrays

Peter Dunne and J. M. D. Coey

Effect of a Magnetic Field in Electroless Plating

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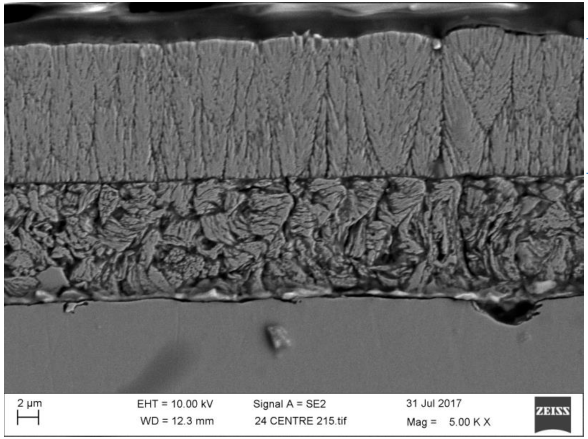
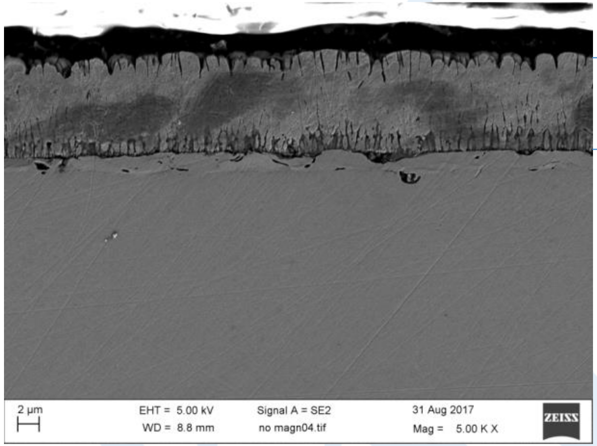
Cross-sectional morphology of Electroless Ni-B Deposit

A - maximum magnetic field influence



10 µm

B - without magnetic field application



5 µm

Danilova, S; Bonin, L; Graves J E; Vitry, V, Cobley A J "The influence of a Gradient Magnetic Field on Ni-B electroless plating", paper in preparation

Effect of a Magnetic Field on Electrochemical Deposition - Recap

Previous work has shown that both electroplating and electroless plating can be influenced by the application of a Magnetic field

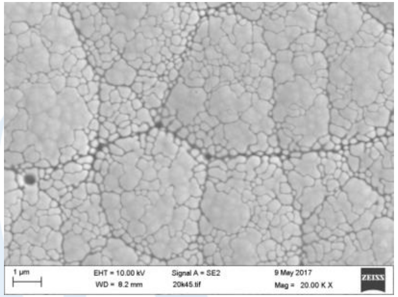
Electroplating

- Patterning possible – but substrate must be conductive
- Layer roughness
- Morphology
- Layer density
- Layer thickness
- Crystal structure
- Corrosion resistance

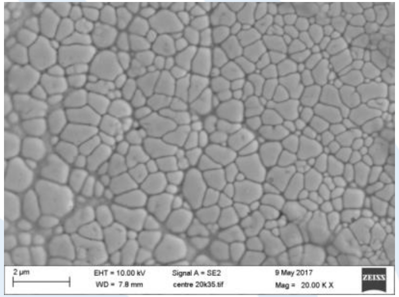
Electroless Plating

- Few studies in this area
- Morphology and crystal structure
- Increased plating rate
- No studies on selective metallisation

Ni-B deposit – No magnetic field



Ni-B deposit – Applied magnetic field



Catalysation of a non-conductive substrate for Electroless Plating

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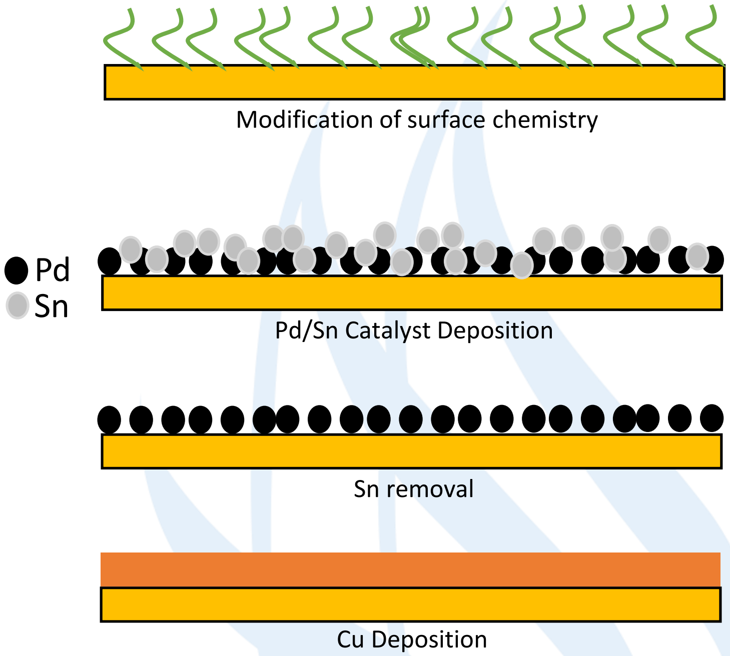
Electroless plating on a non-conductive substrate requires the presence of a catalyst to initiate plating

Conditioner/Sensitizer	**5 minutes**	**30-60 ºC**
Rinse	**5 minutes**	
Pre-dip	**1 minute**	**RT**
Catalyst / Activator	**5 minutes**	**30-50 ºC**
Rinse	**5 minutes**	
(Accelerator	**2 minutes**	**RT)**
Rinse	**3 minutes**	
Electroless Copper	**25-60 minutes**	**30-70 ºC**



Selective Catalysation of a non-conductive substrate by application of a Magnetic Field – The Concept

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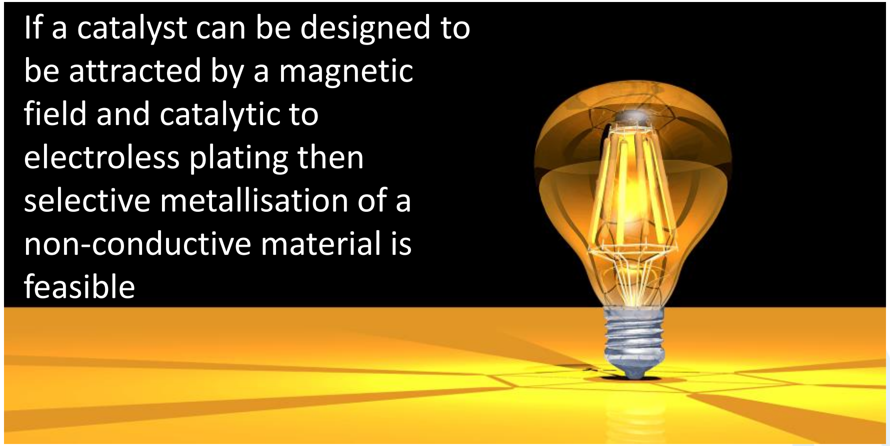

Aims of Phase 1 of research

- Design and synthesise magnetic/catalytic nanoparticles
- Demonstrate that magnetic/catalytic nanoparticles can be selectively deposited on a non-conductive substrate using a magnetic field
- Demonstrate the the magnetic/catalystic nanoparticles will initiate electroless copper deposition

Selective Catalysation of a non-conductive substrate by application of a Magnetic Field – The Concept

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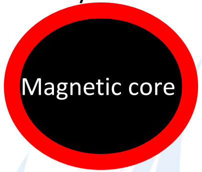
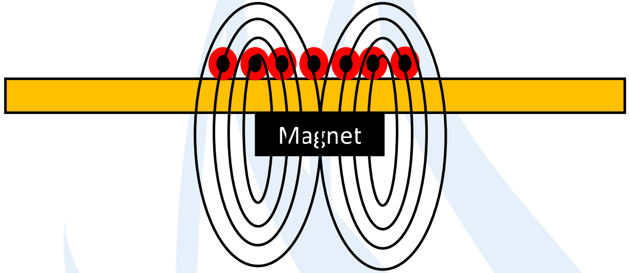
Synthesise a nanoparticle with a magnetic core and a catalytic shell

Catalytic Shell



Selectively deposit the catalyst on a non-conductive substrate using a magnetic field



Selective deposition of catalyst in a magnetic field

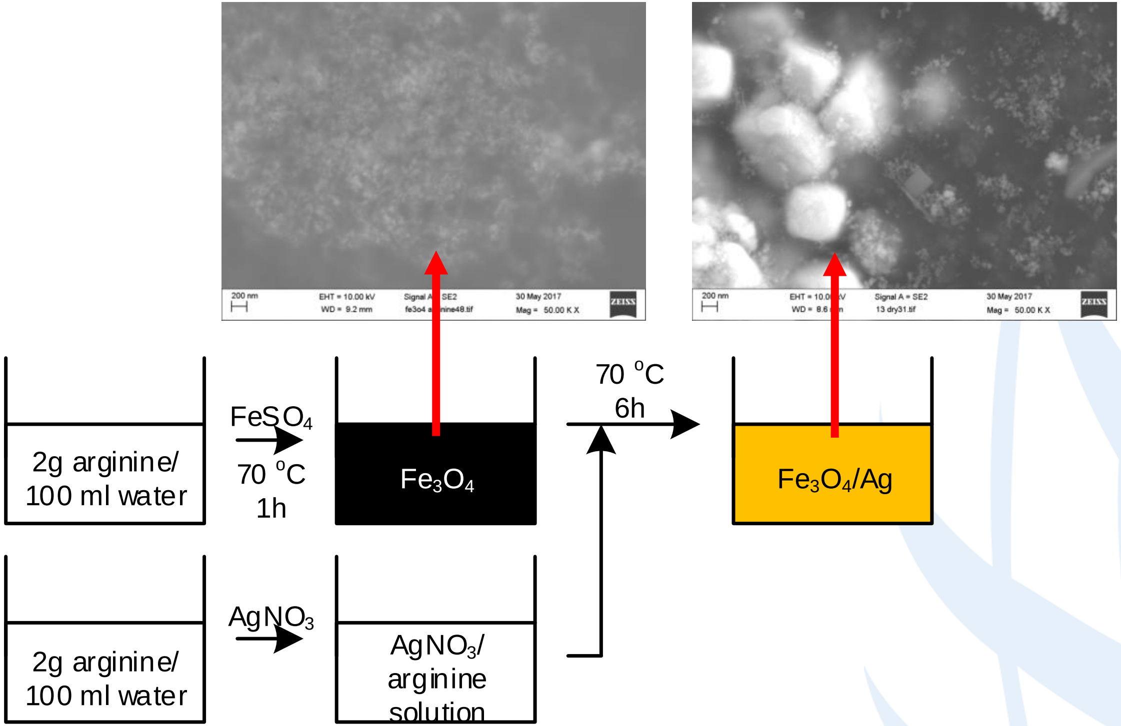
Selectively deposit electroless copper

Selective Cu Deposition

Synthesis of Magnetic-Catalytic Nanoparticles

Literature search identified a procedure for producing Ag-Fe_3O_4 nanoparticles

J. R. Chiou, B. H. Lai, K. C. Hsu, D. H. Chen, One-pot green synthesis of silver/iron oxide composite nanoparticles for 4-nitrophenol reduction, *J. Hazard. Mater.*, 248 (2013) 394-400.



Synthesis of Magnetic-Catalytic Nanoparticles

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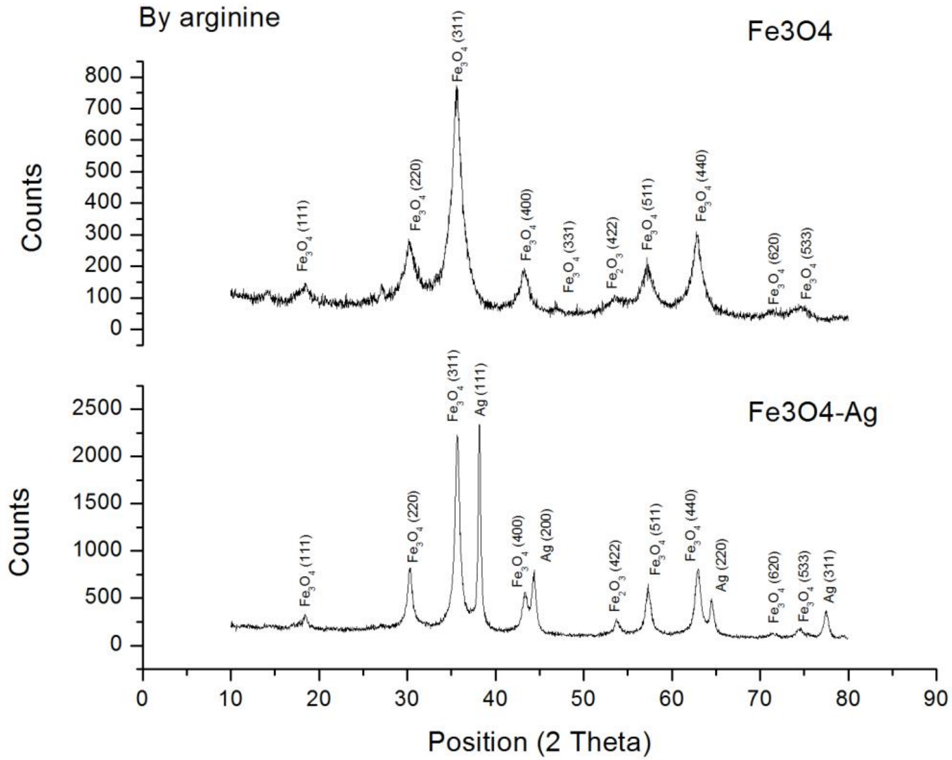
Synthesis of Ag-Fe Nanoparticles using Arginine as reducing agent

XRD Analysis determines that nanoparticles are Ag-Fe_3O_4



Synthesis of Magnetic-Catalytic Nanoparticles

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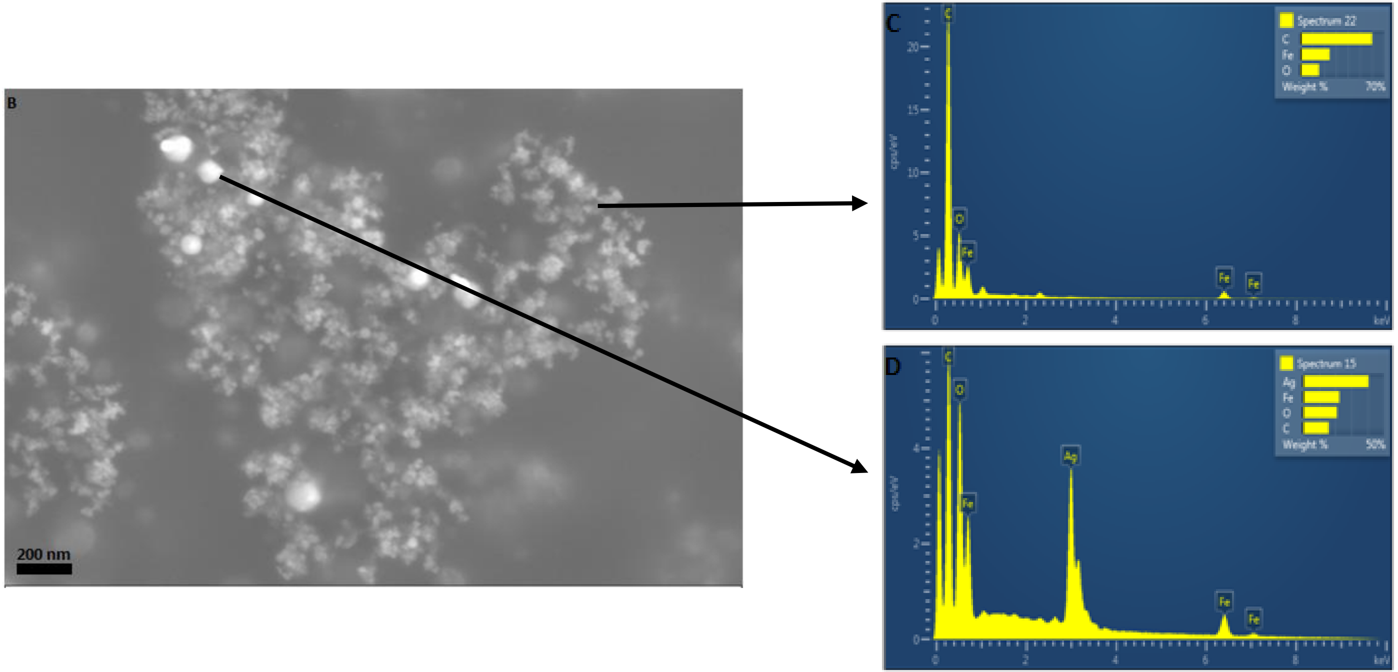
Synthesis of Ag-Fe_3O_4 Nanoparticles using Arginine as reducing agent



SEM-EDX Confirms formation of Ag-Fe_3O_4 Nanoparticles but suggests 'composite' (not core-shell)

TEM Analysis of Fe_3O_4 and Ag-Fe_3O_4 Nanoparticles

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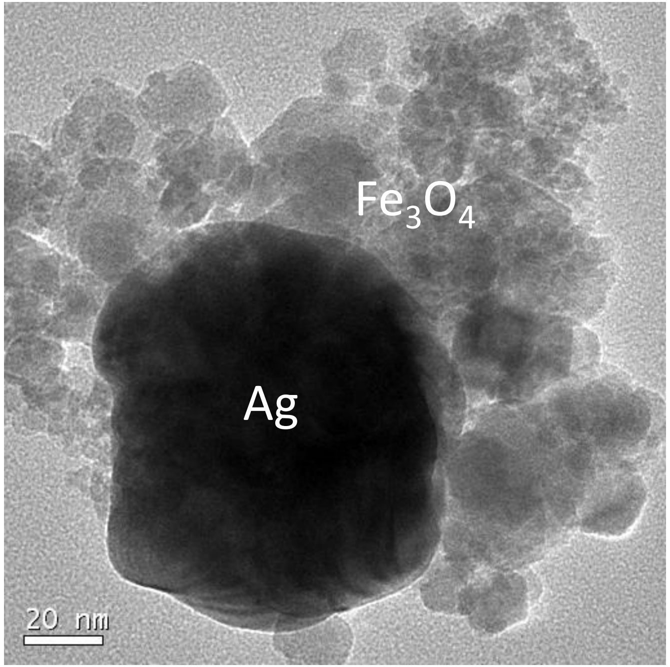

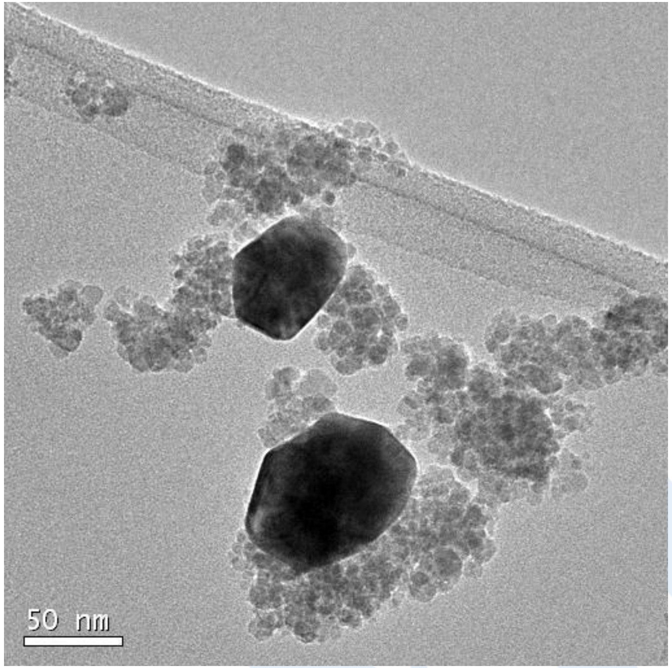

Particle Size Analysis of Fe_3O_4 and $Ag\text{-}Fe_3O_4$ Nanoparticles

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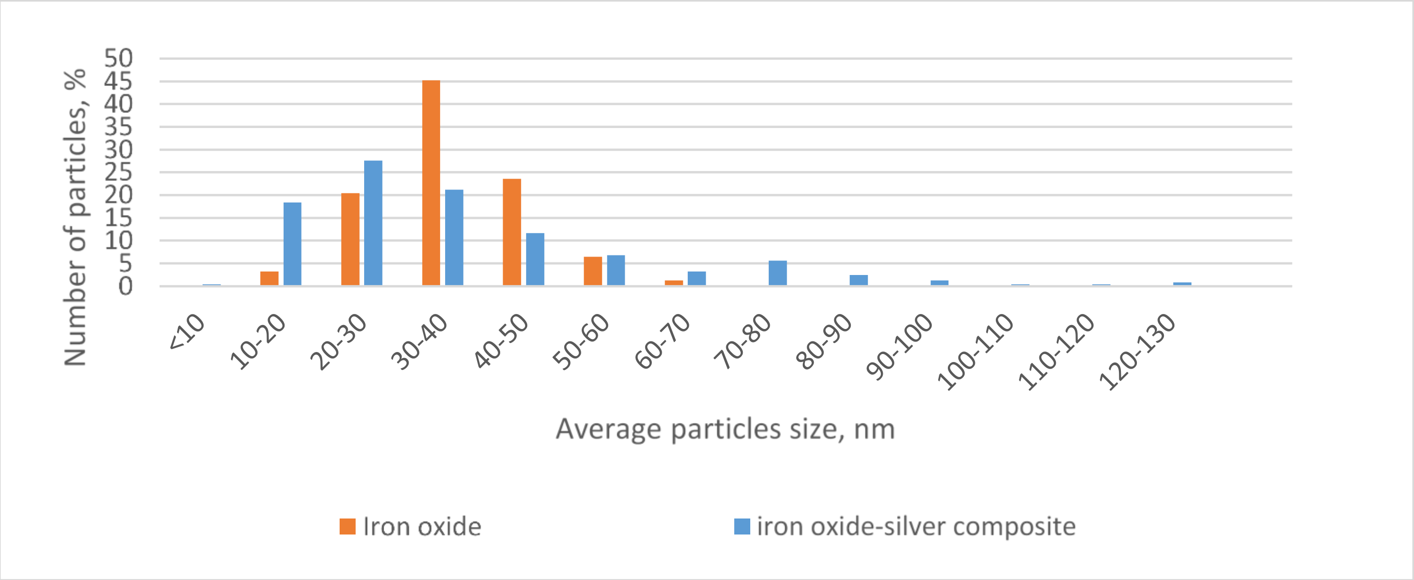

Increase in the formation of larger particles from 60 to 90 nm compared to the Fe_3O_4, where no particles larger than 70 nm are apparent

Are Ag-Fe_3O_4 Nanoparticles Magnetic and Catalytic?

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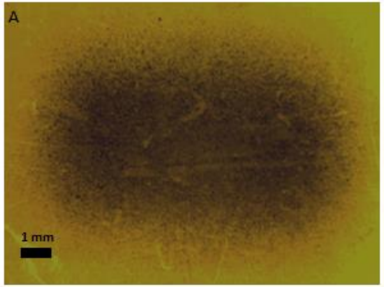
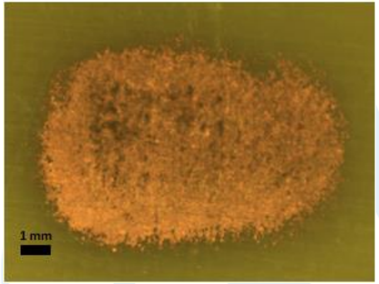
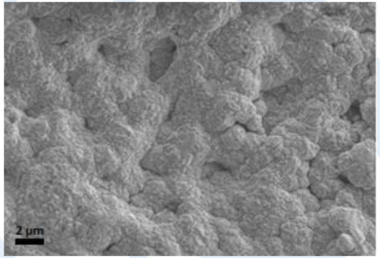
Substrate after selective catalysation in Magnetic Field
Catalyst is selectively deposited



Substrate after electroless copper plating
Selective metallisation has occurred



SEM of electroless copper morphology
Deposit is similar to Pd catalysed deposit although not as uniform

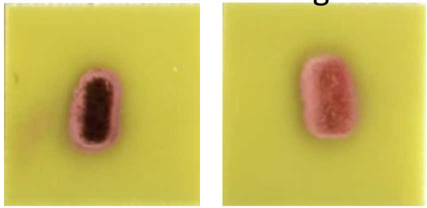


$Ag\text{-}Fe_3O_4$ Nanoparticle Catalyst Optimisation

Catalyst efficacy is effected by various parameters

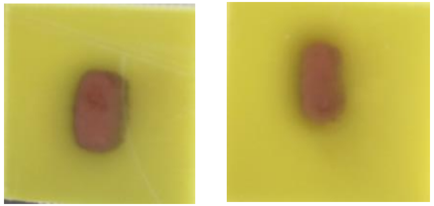
Catalyst Concentration

Low | High



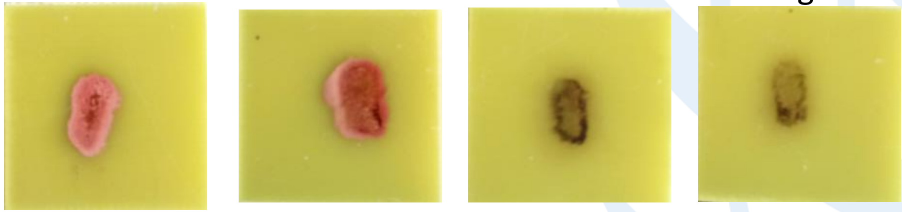
Dispersion Agent

Tween 20 | Tween 80



pH

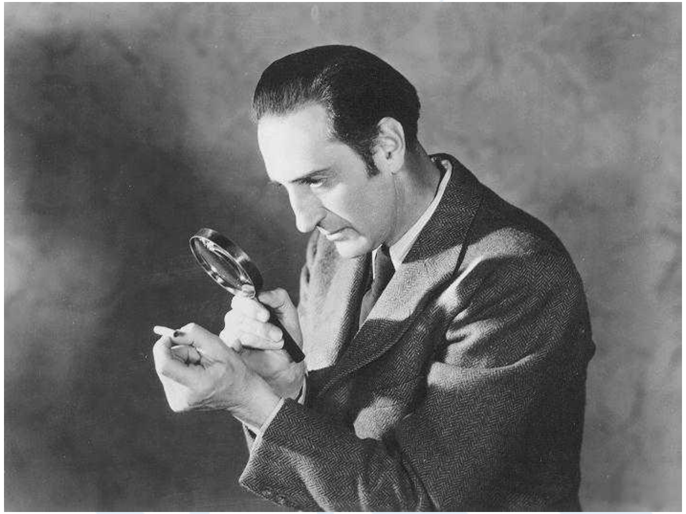
Low → High



Selective Catalysation of Ag-Fe_3O_4 Nanoparticles and Electroless Plating

Selective Metallisation using a Magnetic Field Conclusions

1. The synthesis of a Magnetic / Catalytic nanoparticles has been achieved
2. Analysis has shown that these nanoparticles are composed of Ag and Fe_3O_4
3. The nanoparticles are a composite of Ag and Fe_3O_4 (not core shell)
4. The composite Ag and Fe_3O_4 nanoparticles can be selectively deposited using a magnetic field
5. The composite Ag and Fe_3O_4 nanoparticles are catalytic to electroless copper plating



Selective Metallisation using a Magnetic Field
Further Work

1. Determine Magnetic properties of Ag-Fe_3O_4 catalytic nanoparticles
2. Synthesis of Cu-Fe_3O_4 catalytic nanoparticles
3. Elimination of Fe before deposition (by dissolution)
4. Determine process parameters
    - Catalyst operating parameters – time, temperature, concentration etc.
    - What resolution is achievable?
    - Can more complex patterns be replicated?
5. Identify applications
6. Find commercial partners

Selective Metallisation using a Magnetic Field
IP Protection

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Coventry University has published a patent to cover this work

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(19) World Intellectual Property Organization
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WIPO | PCT

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(54) **Title**: MATERIAL DEPOSITION IN A MAGNETIC FIELD

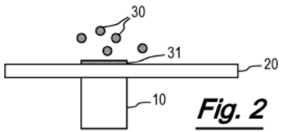

Fig. 2

(57) **Abstract**: The present invention provides for depositing a desired pattern (31) of magnetic material (30) on a non-magnetic substrate (20). Control of the deposition pattern (31) is achieved by use of a magnetised template (10) shaped to correspond to the desired deposition pattern. In use, the template (10) is placed behind the substrate (20). Subsequently, the front surface of the substrate (20) is exposed to a solution containing the magnetic material (30) to be deposited. The magnetic material (30) is attracted to the magnetised template (10) and consequently is deposited in a pattern (31) covering areas corresponding to the shape of the template (10).

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Thank for your Listening

Any Questions?