A new process for electron beam induced deposition of cobalt with excellent properties

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Electron beam induced deposition (EBID) is a well known technique for the direct creation of 3-dimensional structures by computer controlled rastering of the beam in the presence of a precursor gas adsorbed at the surface. Ideally a precursor decomposes into a volatile part that is pumped away and a non-volatile part that forms the newly created structure at the beam impact point. Deposition of Cobalt as a material for nano-scale magnetic structures and components has been reported to provide good purity and relatively good magnetic and transport properties[1]. At the same time other recently reported results show an undesired variation of the main functional properties of the depositions[2] and therefore process repeatability and robustness need further attention. We have investigated the decomposition process of the $Co_2(CO)_8$ precursor in more detail.

As a function of substrate temperature it was found that in fact undergoes through three regimes of decomposition and not two as expected. With increase of temperature the normal EBID process occurs with a decrease of yield by more than one order of magnitude towards higher temperature (~10^{-4} μm^3/nC) and a increase in purity to above 80 at% of Co depending on beam parameters (see Figure 1). Increasing the temperature to above 70ºC induces spontaneous decomposition of $Co_2(CO)_8$ at the surface of the substrate with formation of a thin film of close to 100 at% purity, but patterning capabilities are lost. However, there is an intermediate range of temperatures, between 55ºC and 70ºC where growth of the patterned structures is suddenly enhanced by a factor of 100 (~10^{-2} μm^3/nC yield), while the purity is also close to 100 at%. The omni-directional growth in this region (see Figure 2) is attributed to catalytically stimulated growth using a very thin film of carbon as a seed layer. This seed pattern can be created by a dedicated fast carbon EBID process using for example naphthalene or by decomposition of any residual hydro-carbons in the system. The catalytically enhanced growth regime has been investigated for purity, transport and magnetic properties and has shown to provide excellent properties for structures made between 55 ºC and 65 ºC (Table 1).

Thus three growth regimes are observed. Below 55ºC only conventional EBID occurs and above 70ºC spontaneous decomposition takes place. Between 55ºC and 70ºC one can switch between the standard EBID process (which is slow, but with reasonably high purity) and catalytically enhanced EBID growth on C seed (where both purity and growth rate are very high). Co-existence of the two regimes allows for patterning a combination of high volume structures and small well-controlled nano-scale structures, both with good local properties.

[1] Fernandez-Pacheco A, De Teresa J M, Cordoba R and Ibarra M R 2009 *J. Phys.* D **42** 055005
[2] Utke I, Hoffmann P, Berger R and Scandella L 2002 *Appl.Phys.Lett.* **80** 4792–4

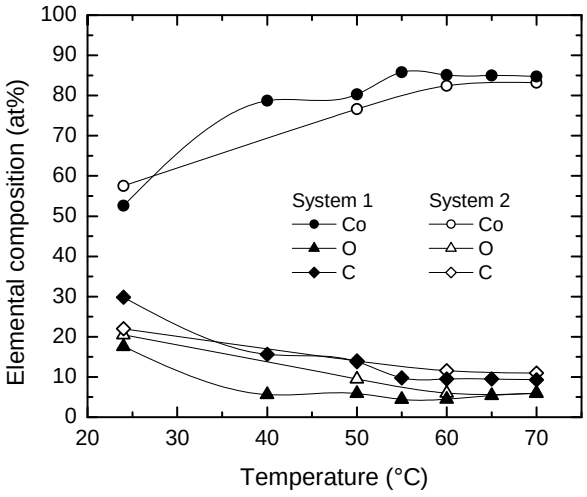

Figure 1: Composition of conventional EBID deposits with $Co_2(CO)_8$ as a function of the substrate temperature. Depositions were done on two different systems using 5 kV and 1 nA current.

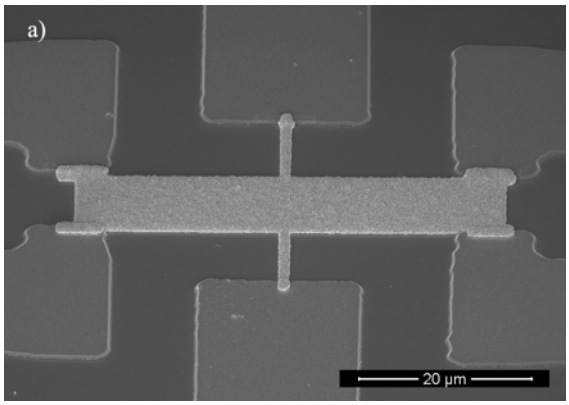

Figure 2: Cobalt wire produced for Hall probe measurements on Si_3N_4 substrate by EBID on C EBID seeds at 65°C at 2 kV, 3.4 nA for 60 min (image is taken at 52° stage tilt).

Table 1. Various transport properties of several samples with deposited Co. The purity at 50 ºC was > 85 at%, while at 58 and 65 ºC the purity is > 98 at%.

Sample	Resistivity (microhom-cm)	Residual Resistivity Ratio	AMR (%)	M_S (Tesla)
50°C standard EBID	152	1.10	0.02	0.9
58°C with carbon seed	22	1.61	1.2	1.25
65°C with carbon seed	21.4	1.81	1.2	1.55