Viewpoint on "Tuning shape, composition and magnetization of three-dimensional cobalt nanowires grown by Focused Electron Beam Induced Deposition (FEBID)"

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The ultimate dream of materials design and fabrication is the ability to build-up materials with single atom precision in terms of positioning control and element selectivity, and to do it in a way that is fast and thus potentially viable as a commercial fabrication technology. While such a 3-dimensional atomic printing technology might stay an elusive goal for decades to come, it is interesting to notice that the reverse is actually already accomplished, namely the atomic scale analysis of materials and devices by means of an atomic probe system, which allows for the simultaneous chemical element analysis and atomic position measurement [1], even though it is a destructive technique.

One approach that has been pursued during the past three decades, and which has resulted in amazing scientific results, is based on the ability of Scanning Tunnel Microscopy (STM) tips to pick up and place individual atoms precisely onto surfaces [2]. This allowed for the fabrication of complex planar structures that are a most relevant tool in the exploration of surface phenomena and especially quantum mechanical interference effects at surfaces [3]. While this technique has been used for a number of chemical elements, and even allowed for the recording of an atom-scale movie [4], it requires not only a very specialized tool, but its operation is extremely slow. Moreover, this slowness appears to be an inherent limitation, because either the substrate or the STM tip unit, and thus significant masses, have to be moved for its operation. For the same reason potential parallelization does not seem to be a viable option, even if tip arrays were considered for storage applications in the past [5]. Another approach that aims towards atomic printing is Focused Electron Beam Induced Deposition (FEBID), which is the very methodology that was used by Pablo-Navarro et al. in their recent publication [6]. In principle, FEBID could lead to almost atomic scale deposition precision, it has chemical design capabilities by means of the use of different precursors, and in principle, it could be very fast, because it relies only on electrons and molecules as its “moving parts”, and correspondingly it could also be parallelized.

Present day FEBID technology is still far from this ultimate goal in materials fabrication, but very substantial progress has been made in recent years [7]. Also, relevant progress has been made on 3-dimensional growth of magnetic materials via FEBID [8], whereas earlier work has been more focused on planar type structures [9]. 3-dimensional structures are hereby especially interesting because other nano-fabrication techniques, which frequently utilize lift-off nano-lithography, do not tend to work very well for nanostructures that have very significant depth and depth dependent shapes. In this scenario, the letter by Pablo-Navarro et al. [6] is very relevant and timely, because it demonstrates achievable key performance indicators for making 3-dimensional functional structures, namely shape, composition and magnetization. In particular, the authors identify two growth mechanisms, to which they refer as radial and linear growth modes, whose occurrence depends in a quite sensitive fashion on the experimental parameters, under which the structures are produced. Importantly, they also observe dynamic transitions in between the growth modes that are triggered by the growing 3-dimensional structure itself, due to the impact that it has onto the experimental operation conditions [6]. Thus, the work also illustrates very clearly the practical challenges of FEBID growth of magnetic nanostructures:

(I) All materials aspects, such as topography and composition that produce a Secondary Electron (SE) Microscopy contrast, which make it such an extremely valuable characterization technique, also impact FEBID growth, including the growing FEBID structure itself. In turn, this will require design rules or deposition parameter adaptation, when a predesigned structure is translated into sequential fabrication steps.

(II) The precursor adsorption capacity and adsorbate mobility is superimposed onto the SE yield and has to be considered in the design of an actual fabrication sequence. This is very difficult to control directly during the growth process, so that libraries of material and shape combinations will have to be measured and catalogued.

(III) The availability and efficiency of suitable precursor materials is still a relevant limitation and many more materials ought to be explored and possibly synthesized for the purpose of FEBID use. However, this is a realistic path only, if relevant applications can be found and the corresponding precursor synthesis work incentivised.

(IV) The removal of non-metallic fragments, in particular carbon and oxygen, remains a very relevant problem, and is actually substantially worse for many materials other than the Co-precursor that was used in the study by Pablo-Navarro et al. [6]. In contrast to challenges (I) – (III), this might be the most fundamentally limiting challenge, given that it is inherently connected to the way FEBID operates. Here, much fundamental work, also in terms of simulations, is needed to make relevant progress.

Despite these significant challenges, numerous examples of successful 3-dimensional growth exist and even operational magnetic devices have already been demonstrated [8], but further steps towards an understanding of the complexity of the growth mechanism are needed and ought to be explored. It may also be necessary to improve upon the experimental tools that are available today, and overcome their still existing limitations despite their overall sophistication. For substantial future progress, it seems necessary that proper micro-technology will have to be implemented to control gas flows very close to the deposition region, and overall vacuum conditions will need to be improved as well to have a chance to allow for direct writing of materials with single digit per cent control of the stoichiometry. For that, it would be important to find at least some niche application, in which FEBID could be utilized on a commercial level, and which would allow the influx of ideas and resources by means of actual product level needs and demands.

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