Characterization of Au-Fe nanocrystals obtained by MBE

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Bimetallic magnetic nanomaterials are under extensive investigations now due to their possible application in nanotechnology and nanomedicine. The distinctive characteristic of such materials is their superparamagnetic behavior, which is important for biomedical, diagnostic and therapeutic applications. At present, the Au-Fe based nanomaterials attract much attention due to higher saturation magnetization in comparison with the Au-Fe oxide core-shell structures, which synthesis has heavily been investigated over the last decade [1]. So far, several scientific reports about the synthesis of the Au-Fe core-shell nanostructures have been made. It is clear that this question has not been illuminated enough yet in the literature. That variety of different possible forms of nanostructures, that The Au-Fe system potentially encloses, give us a hope to understand and establish the relationship between technological procedures of their synthesis and resultant properties desirable for practical application.

Hybrid crystalline Au-Fe nanoparticles have been successfully synthesized using the epitaxial growth process. The first step in fine particle characterization was to observe the particles using atomic force microscopy (Fig. 1).

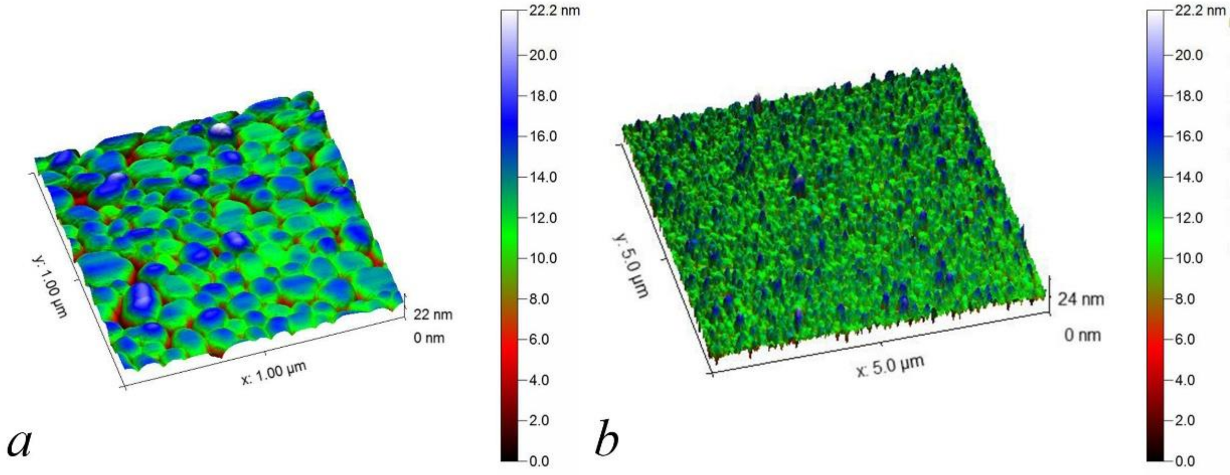

Figure 1. 3D AFM images of hybrid crystalline Au-Fe nanoparticles (a) 1×1 μm^2, (b) 5×5 μm^2.

AFM measurements have better resolution than traditional instruments and can be applied for measurements of bare and untreated surfaces without complicated sample preparations. Precise information about the height of nanocrystalls could be extracted (Fig. 2).

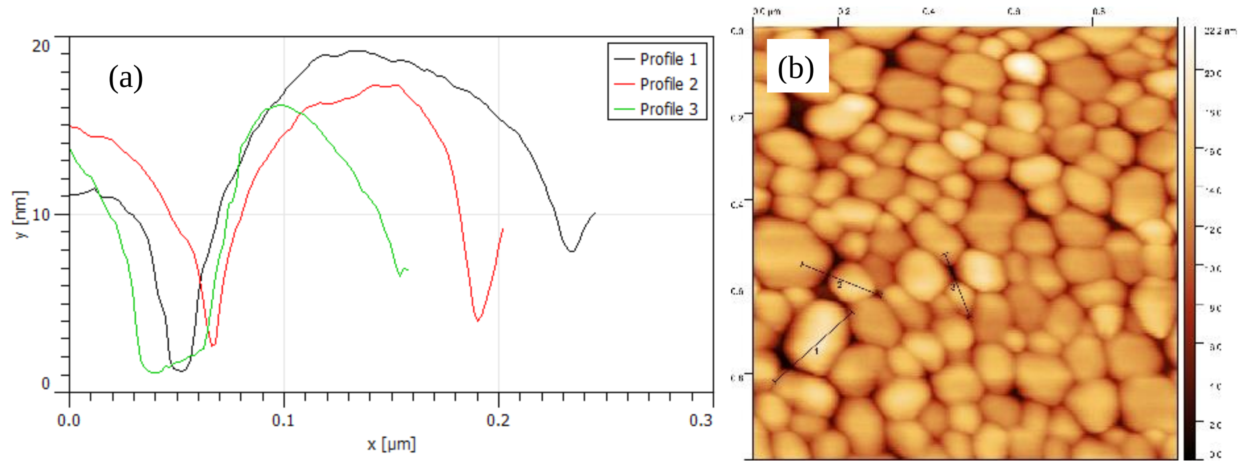

Figure 2. (a) 1D profile and (b) surface map of AFM measurements of Au-Fe nanocrystalls.

The next step was to get most common measurements that are related to the width and shape of the particle distribution. Firstly, it is possible to process the measurements based on the level of assumptions and the degree to which the results are calculated. For instance, the first measurement is the projected two-dimensional area, which is calculated as the sum of the areas of each individual pixel (Fig. 3a). So, most of the nanocrystals have area near 100 nm^2. Using various equations we can calculate the aspect ratio. Modern literature defines aspect ratio as the ratio of the Feret's minimum length to the Feret's maximum length [2]. The maximum Feret's diameter, also called the maximum distance in some references, is defined as the furthest distance between any two parallel tangents on the particle. Likewise, the minimum Feret's diameter, also called the minimum distance in some references, is defined as the shortest distance between any two parallel tangents on the particle. Thus, as the width and length of the shape approach the same value, the aspect ratio approaches one. This does not necessarily mean the shape is circular, though a perfect circle does have an aspect ratio of 1.0. Often very symmetric shapes also have a very high aspect ratio (Fig.3b). In our work most of hybrid crystalline Au-Fe nanoparticles have aspect ratio close to 0.5.

Furthermore, circularity was defined as the degree to which the particle is similar to a circle, taking into consideration the smoothness of the perimeter. This means circularity is a measurement of both the particle form and roughness. Thus, the further away from a perfectly round and smooth circle that a particle becomes, the lower the circularity value. Circularity is a function of the area divided by the square of the perimeter. Conversely, as a shape becomes less round or as the shape becomes less smooth, the circularity should approach zero. Most of synthesized crystalline Au-Fe nanoparticles have circularity close to 0.9. This analysis shows that the most of particles have shape closed to spherical (Fig. 3c).

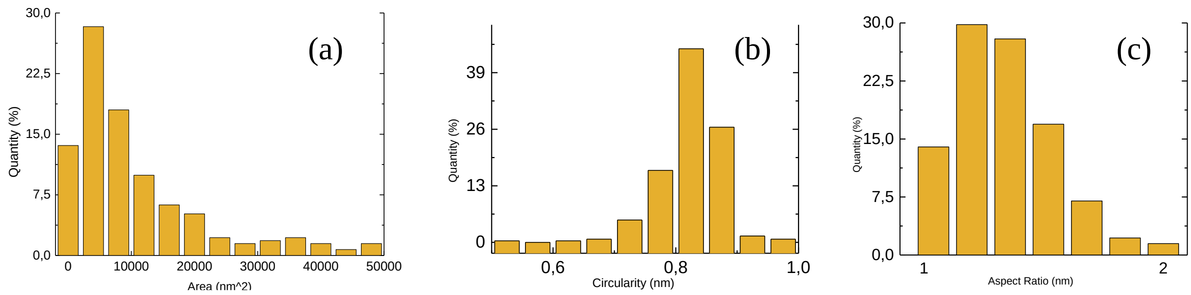

Figure 3. Histogram distributions of area (a), circularity (b) and aspect ratio (c) measurements of Au-Fe nanocrystalls.

Using these measurements may not be adequate to describe a typical non-spherical particle with some degree of surface roughness. There are various definitions and several standardized shape factors available that can provide additional descriptors to a particle population of interest. These valuable shape descriptors can be measured using image analysis. There are numerous examples of how the shape of the particle may influence its behavior or correlate to a response of interest. Because of this importance, shape factors may be necessary to consider in validated characterization methods.

Hybrid crystalline Au-Fe nanoparticles are perspective candidates for solving the problem of increasing the density of information recording on non-volatile media. Despite the high cost of gold, its insolubility in iron in bulk materials makes it possible to form thin shells on the faces of iron nanocrystals due to phase segregation at high temperatures [3], which allows using the least amount of the expensive metal. Besides, having strong spin-orbital coupling and resistance to oxidation, gold provides opportunities for improving the magnetic characteristics of hybrid nanocrystals based on Au-Fe.

1. Z.D. Pozun, S.E. Rodenbusch, E. Keller, et al., *J. Phys. Chem*. **117**, 7598 (2013).
2. E.G. Michel, *Appl. Surf. Sci*. **117**, 294 (1997).
3. M. Benoit, N. Tarrat, *J. Morillo, Phys. Chem*. **18**, 9112 (2016).