Synthesis of Fe-Au nanoparticles through phase separation using the gas aggregation technique

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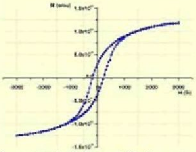
ABSTRACT

During the last years different type of magnetic materials have been obtained either alloys or nanoparticles with several metallic shells. These particles exhibit better magnetic properties, are biocompatible and have optical properties due to their shell noble metal layer. It is possible to synthesize heterostructured nanoparticles with core/shell structure by using sputtering targets consisting of alloys of different materials. In the case of such materials have different surface energies and atomic sizes, there are diffusion processes which lead to the formation of structured nanoparticles with a shell and core having different composition [1].

In this work, we will show the results obtained about Fe-Au nanoparticles grown by the gas aggregation technique, using magnetron sputtering sources. Colloids prepared from sputtered deposits of heterostructed nanoparticles exhibit less aggregation when compared to suspensions obtained from pure magnetic materials. Spectrophotometry measurements show the presence of gold at the surface of the nanoparticles. Magnetic properties of such particles are analyzed by VSM. Composition and structural analysis are studied by TEM and EDAX.

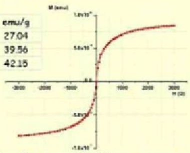
MAGNETIC PROPERTIES

Fe nanoparticles, 0.5mbar, 45W

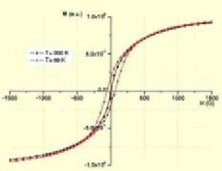


Fe-Au nanoparticles, 0.5mbar, 45W

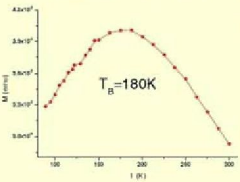
P(mbar)	emu/g
0.5	27.04
0.7	39.56
0.8	42.15



Comparing both Fe and Fe-Au nanoparticles, grown under the same conditions, we can see that the last ones show a superparamagnetic behavior due to the structure of the nanoparticles which consists on small grain of gold and iron. Nanoparticle size increases with pressure, and specific magnetic moment tends to that of iron content.



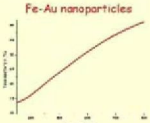
Fe-Au nanoparticles, ZFC curve



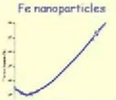
OPTICAL PROPERTIES

Colloids are prepared by scratching the deposited material onto water and applying a brief sonication. Optical properties are measured in a Spectrophotometer Jasco V-650.

Fe-Au nanoparticles

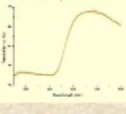


Fe nanoparticles



Optical transmittance measurements do not reveal a maximum absorbance in the range 350-800nm in contrast to pure Au and Fe nanoparticles. However it is observed a larger dependence on light wavelength as shown in figures.

Au nanoparticles



CONCLUSIONS

- Low phase segregation is found on Fe-Au nanoparticles obtained under the conditions described above. This effect may be originated from the nucleation of Au nanoparticles in the volume around the Au inclusions in the sputtering target that results afterwards more difficult to segregate.
- Particles are mainly nanocrystallized containing grains of Fe and Au at a proportion close to that in the original target.
- Magnetic measurements show superparamagnetic behaviour at room temperature for a wider range of diameters as compared to pure Fe nanoparticles [3].
- Larger material production rate is obtained when compared to pure Fe grown under the same conditions.

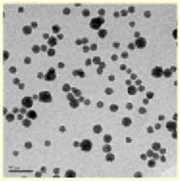
TARGET AND SOURCE SET-UP

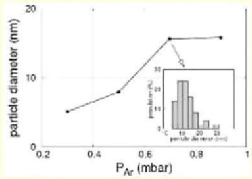
The system is based on a sputtering gun with an aggregation chamber where the high pressure promotes aggregation of atoms into small particles that are transported out by the gas flow.

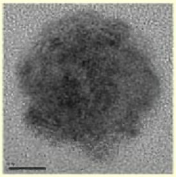
The target contains small pieces of Au (few milimeters in size) that are embedded in a bulk Fe matrix. The proportion between Fe and Au is 50% in weight each. The aggregation gas contains atoms of both species.

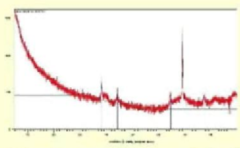
STRUCTURE

Nanoparticle size ranges from 5nm (at 0.3mbar of inert gas pressure) to 16nm (at 0.9 mbar). Deposition rate is maximum for the maximum particle size with a growing rate close to 3mg/h. Particle size dispersion has a standard deviation about 20%.

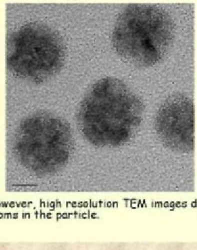


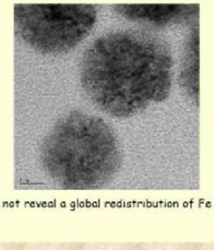






Particles are nanocrystallized in small Fe and Au grains. Fe is identified from atomic planes distance in HRTEM images while Au is identified from x-rays analysis.





However, high resolution TEM images does not reveal a global redistribution of Fe and Au atoms in the particle.

ACKNOWLEDGMENTS

This work has been supported by Ministerio de Educación y Ciencia under the project MAT2007-65965-C02-01 and Comunidad de Madrid under the project SAL-0312/2006. We thank CAI (UCM) for the TEM and X-Rays analysis.

REFERENCES

[1] Y.H. Xu, J.P. Wang. *"Direct Gas-Phase Synthesis of Heterostructured Nanoparticles through Phase Separation and Surface Segregation"*. Adv. Mater. 20 (2008) 994

[2] T.L. Kline, Y.H. Xu, Y. Jing, J.P. Wang, *"Biocompatible high-moment FeCo-Au magnetic nanoparticles for magnetic hyperthermia treatment optimization"*, JMMM 321 (2009) 1525–1528

[3] Y. Qiang, J. Antony, M.G. Marino, and S. Peadyala, *"Synthesis of Core-Shell Nanoclusters with High Magnetic Moment for Biomedical Applications"*, IEEE Trans. on Magn. 40 (6) (2004) 3538-3540