Nanoscale Pattern Formation by (Directed) Self-Assembly: Science, Schema, and Functionality

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Abstract:
I will discuss two seeming very different forms of self-assembly to produce nanoscale pattern formation in materials, one occurring in epitaxial semiconductor thin films, the other occurring in bulk metallic alloys. While very different processing is involved, pattern formation and lengthscales in both systems are dictated by the competition between elastic and interfacial energy. The first example has some resonance with long-standing research efforts at UNM – directed self-assembly of epitaxial quantum dots (QDs) during molecular beam epitaxy, in my case in the Si-Ge system. Our ultimate goal is a 3D *quantum dot mesocrystal* on lengthscales fine enough to promote formation of vertical 2D conduction channels. Our study to date has focused on the all-important first layer of SiGe QDs, grown on a surface pattern on Si (001) formed by electron-beam lithography. The key scientific question we've explored relates to the interplay of the intrinsic (due to strain) and extrinsic (due to patterning) lengthscales. Indeed, while QDs show a very strong and well-understood tendency to form at the bottoms of discrete pits in the substrate (defined by lithography), we find a narrow regime where the QDs suddenly bifurcate in volume and move to a new location in the pattern that is not predicted by existing theory. We use an in situ annealing approach to gain better control over QD size, but we may then lose control over composition. In the second part of my talk I will discuss exchange-coupled ferromagnetism in bulk Co-Pt alloys. We exploit the eutectoid phase transformation to self-assemble the novel nanochessboard structure, which is a 2+1D quasi-periodic tiling of $L1_0$ and $L1_2$ ordered phases on the 15-40 nm lengthscale. The $L1_0$($L1_2$) phase has high(low) magnetocrystalline anisotropy, and can exchange couple across their fully coherent interfaces. We used first-order reversal curve (FORC) analysis to show that exchange coupling can become complete when the chessboard lengthscale is driven below the critical coupling dimension. However, micromagnetics simulations suggest that the dependence of the coercivity on lengthscale is complex, owing to the inherent nature of the chessboard. I gratefully acknowledge support from the II-VI Foundation, and the NSF under grant DMR-1105336.

Brief biosketch:
Jerry Floro is a professor of materials science and engineering at the University of Virginia, where he has been since 2006. Prior to joining academia, he spent 14 years on the technical staff at Sandia National Laboratories. Floro earned his Ph.D. at MIT in materials science, his B.S. in Physics from Colorado State University, and spent 3 years in between as a thin film engineer at IBM Watson Research in Yorktown Heights, NY. In addition to research on materials processing and structure, Floro has an abiding interest in evidence-driven pedagogical methods to improve undergraduate learning.