Editorial: Efficient Experimentation in Nanomanufacturing

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Recent years have seen incredible growth in the area of nanotechnology, an idea attributed to Nobel laureate Richard Feynman. In his visionary 1959 lecture titled ‘There is Plenty of Room at the Bottom’ he made bold and accurate prognostications on building molecular scale machines (Feynman, 1960). This idea perhaps invokes some sense of science fiction, and indeed nanomotors that can be used to rotate microscale objects has been addressed (Eelkema et al., 2006).

More broadly, the power of nanomanufacturing emphasises the use of nanotechnology for manufacturing the products and services we use everyday. One of the foremost challenges nanomanufacturing faces is that of scaling up. A National Science Foundation report says,

> "To move scientific discoveries from the laboratory to commercial products, a completely different set of fundamental research issues must be addressed–primarily those related to viable commercial scale-up of production volumes, process robustness and reliability, and integration of nanoscale structures and devices into microscale, mesoscale and macroscale products" (Busnaina et al., 2003).

Achieving this goal relies in part on careful, efficient experimentation. All too often, however, we see papers in the nanotechnology literature in which a one-factor-at-a-time experimental approach has been applied. This approach is so-named because the experimenter tries to change one factor while holding all of the others constant. Although it appears to be a methodical approach on the surface, as explained in the classic *Design and Analysis of Experiments* (Montgomery, 2005), its use is unfortunate because it often misses important interactions among the variables, yielding misleading conclusions. The idea for creating this Special Issue came out of a need to address this confusion as it pertains to nanomanufacturing research.

The issue presents seven papers that cover a range of DOE methods. I give a brief introduction of these papers below. What they have in common is that they are all using the statistical framework to methodically drive efficient experimentation and development in nanomanufacturing.

The first paper, 'Understanding conductivity in a composite resign with Single Wall Carbon Nanotubes (SWCNTs) using Design of Experiments', by S. Desai, R. Mohan, J. Sankar and T. Tiano uses a 2^3 *factorial design* to study the coupled effect of the weight% SWNT, polymer composite preparation method, and position of measurement on the DC conductivity.

The second paper, 'Characterisation of the SilSpin Etch-Back process for nanolithography with CHF_3 and O_2 gas chemistry', by H. Carrion, M. Rogosky, H.B. Nembhard, S. Joshi, and J. M. Catchmark uses a 2^4 *factorial design* to study the relationships between the process factors (reactor pressure, power, gas flow and magnetic flux) and the etch responses.

The third paper, 'Understanding a ZnO nanorods fabrication process: a supersaturated design approach', by N.N. Acharya and D.K.J. Lin uses a *supersaturated design* to study nine factors (including substrate, carrier gas, process temperature, optical density of the bacteria) on the ability to grow ZnO nanorods with consistent measurements of surface roughness.

The fourth paper, 'Statistical design and analysis for a three-step surface initiated polymerisation process', by N. Acharya and H.B. Nembhard uses a multistage split plot design to study a total of seven factors (including amount of catalyst, type of rinsing solvent and reaction temperature) that appear in two stages of the manufacturing process.

The fifth paper, 'RSM-based Optimisation for the processing of nanoparticulate SOFC anode material', by G. Rajaram, S. Desai, Z. Xu, D.M. Pai and J. Sankar uses a Central Composite Design (CCD) as the basis for applying *response surface methodology* to understand the relationship between porosity and electronic conductivity of a nickel-yttria stabilised zirconia.

The sixth paper, 'Investigation of cell gap on the polymer substrates using statistical modelling for flexible liquid crystal display applications', by Y-D. Ko, J-Y. Hwang, D-S. Seo and I. Yun uses a *D-optimal design* along with a desirability function to study the effect of three factors (spacer, pressure and iron sheet) on two responses (two cell cap measurements).

The seventh paper, 'A case study comparison of alternative meta-modelling methods related to nanoenabled surgical instrument design', by M. Aguirre, M. Frecker and H.B. Nembhard compares five models – *CCD, face-centered CCD, Box-Behnken design,* 3^k *factorial design* and *Latin hypercube design* – on their ability to predict the performance of a surgical instrument.

We hope that you enjoy reading this Special Issue and that it may inspire further work in the integration of design of experiments with nanomanufacturing. We would like to take this opportunity to thank all of the authors and reviewers who have contributed to this issue. All comments and suggestions concerning the Special Issue are welcome.

References

Busnaina, A., Barry, C. and Miller, G. (2003) *Organizers, NSF Workshop on Three Dimensional Nanomanufacturing: Partnering with Industry; Conclusions and Report*, Available at: www.coe.neu.edu/Research/nano/nsf_workshop.htm. Accessed on January 2006.

Eelkema, R., Pollard, M.M., Vicario, J., Katsonis, N., Ramon, B.S., Bastiaansen, C.W.M., Broer, D.J. and Feringa, B.L. (2006) 'Molecular machines: nanomotor rotates microscale objects', *Nature*, Vol. 440, No. 7081, pp.163–173.

Feynman, R.P. (1960) 'There is plenty of room at the bottom: an invitation to enter a new field of physics', *Engineering and Science*, Available on the web in several locations including www.zyvex.com/nanotech/feynman.html.

Montgomery, D.C. (2005) *Design and Analysis of Experiments*, 5th edition, John Wiley & Sons.