Randall M. Erb

Research Statement

Introduction

The programmable manipulation of particles ranging from colloids to biomaterial has become a desired feature in fields from particle physics to bioengineering. To create controlled particle structures, many manipulation strategies have been investigated including lithography, optical trapping, electrophoresis, and magnetophoresis. Of these, magnetophoresis offers the important advantages of strong manipulation forces and high bio-compatibility, encouraging its extensive integration into manipulation technology[1]. With increased focus on nanotechnology, manipulation is required of smaller particles where Brownian motion often inhibits precise particle control. However, if the Brownian motion can be appropriately harnessed, magnetophoresis is still capable of producing useful systems at these scales[2]. To this end, I have both generated several novel magnetophoretic techniques capable of assembling complex particle ensembles, as well as developed theoretical and numerical models that proficiently describe these techniques even under the influence of Brownian motion.

Magnetic Assembly - from Particles to Mammalian Cells

I have demonstrated the assembly and alignment of magnetic and nonmagnetic microparticles inside ferrofluid into intricate colloidal superstructures or formations using magnetic forces, including aligned nanorods[3] and Saturn or Daisy formations[4]. I have derived analytic models revealing the required magnetic energy that leads to proper rod alignment or formation of these structures. As the magnetic energy is decreased, through smaller particle sizes or weaker fields, the models take into account increased disturbance by Brownian motion. I am currently working towards systematically testing these assembly models across a variety of particle sizes ranging from 10 μm to 100 nm. In addition to colloids, I have demonstrated the formation of chains of mammalian cells submerged in biocompatible ferrofluids under applied fields[5]. In ongoing work, I am attempting to stabilize chains of endothelial cells into linear tissues that undergo angiogenesis leading to engineered blood vessels.

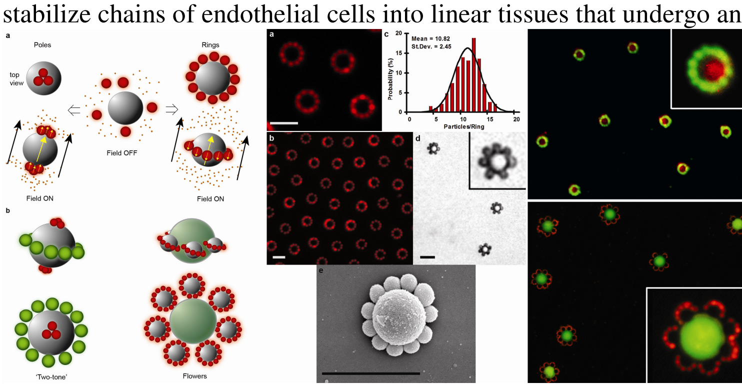

Figure 1 – Here I demonstrate magnetically actuated self-assembly of many complex microstructures including Saturn, Flower, and Two-tone assemblies. These structures have applications in SERS, meta-materials, and SPR. This work was published in February of 2009 in *Nature*.

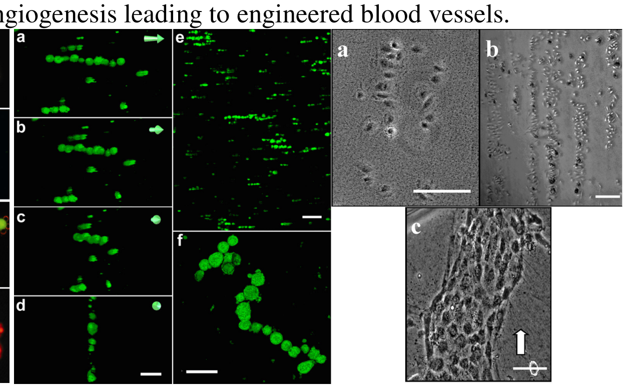

Figure 2 – Here I have shown that label-free endothelial cells could be driven to self-assembly into linear chains by using biocompatible magnetic liquid. This work is currently under review at *NanoLetters*.

Opto-Magnetic Manipulation for Total Particle Control

Also, I have fabricated a new genre of 'dot' metallic Janus particles with a novel soft lithographic technique. This class of particles has been engineered to be the first Janus particles that are compatible with optical trapping methods. With these particles, I have demonstrated control over all 12 degrees of freedom of these particles on a hybrid optical/magnetic platform[6]. This system opens the door for new physical analysis of colloid interactions including rotationally-specific particle assemblies, precise molecular pulling and/or twisting measurements, and new possibilities for on-chip microfluidic systems.

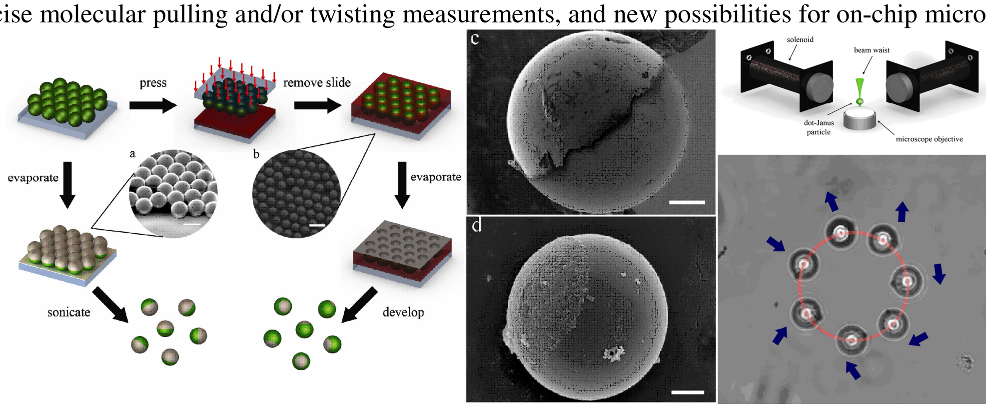

Figure 3 – Here I have developed a novel soft lithographic technique for producing unique 'dot' Janus particles with less metallic surface coverage than conventional 'half' Janus particles. Unlike 'half' Janus particles, 'dot' Janus particles are stable in optical traps and I have demonstrated for the first time the full 12 degrees of freedom control of particles using a combination of magnetic fields and optical tweezers. This work is currently being submitted to *Nature Materials*.

Lab-on-a-Chip Magnetic Systems

Additionally, I have developed substrate-based techniques that can manipulate both magnetic and nonmagnetic particles near a surface. I have demonstrated for magnetic particles the utility of a non-linear particle transporter capable of detecting nominal differences in particle sizes and chemistries[7]. I have also established nonmagnetic particle arrays[8] using templated substrates. Further, I have investigated low magnetic-energy systems of magnetic[9] and nonmagnetic[10] nanoparticles that form local concentration gradients. In each case, I have developed models that describe these assemblies without requiring computation of individual particle trajectories. Instead, probabilistic particle distributions are calculated using Boltzmann statistics. I plan to continue these topics by exploring more complex systems of multiple particle types in order to form co-particle arrays such as binary arrays of two different cell types for cellular communication studies.

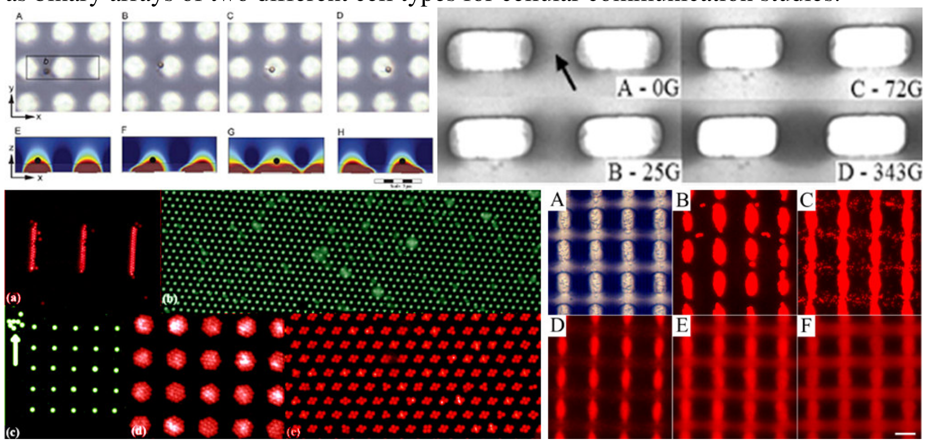

Figure 4 – Here I have developed many magnetic chip-based systems for the manipulation, transport, and detection of magnetic and nonmagnetic particles using conventional and inverse magnetophoresis, respectively.

Developing Fundamental Theories and Numerical Modeling

While developing the aggregation models to describe the chaining kinetics that occur with mammalian cells in biocompatible ferrofluids under applied magnetic fields, I made an important discovery. I have substantiated that while smaller Brownian-affected particles (<4μm) aggregate according to established diffusion limited cluster aggregation (DLCA) models, larger particles (>4μm) instead follow an entirely new model[11] with new dependence on many variables including particle concentrations, field strength, and particle sizes. I am continuing this work with further investigations toward the boundary regime separating DLCA and non-DLCA systems.

Related to my experimental and theoretical work, I have also been incorporating numerical modeling into my research. For example, I have developed a model for the detection of nonmagnetic biological particles in an inverse ferrofluid. This work required comparing a developed model with an exact numeric model in bispherical coordinates[12].

Magnetic Tweezers for Measuring Bond Strengths

Additionally, I have been working on the developing fundamental magnetic physics phenomenon into a working system for both molecular pulling experiments, as well as for properly calibrating AFM tips. I have been studying the magnetic image force that exists in ferrofluid systems[12] and, for the first time, have shown that this image force can be quantified accurately for colloidal systems[13]. With a quantified colloidal force calibrated according to well-established gravitational laws, I can begin measuring exact molecular forces between colloids and surfaces, which has the exciting opportunity for becoming the standard method for calibrating these forces which are very much accepted as just relative measurements up to now.

Clearly, I have generated several magnetophoretic systems for particle manipulation, as well as developed theoretical and numerical models that proficiently describe these techniques even under the influence of Brownian motion. Also, I attempted to highlight some remaining work that I am working to accomplish to further advance these systems in the near future. My desire for future research is to continue any of these projects toward further development and to tackle entirely new systems towards meaningful applications.

References

[1] R. M. Erb and B. B. Yellen. “Magnetic Manipulation of Colloidal Particles”, Nanoscale Magnetic Materials and Applications. Edited by J. P. Liu, et. al. Springer Publishing Company, In Press.

[2] B. B. Yellen and R. M. Erb. “Manipulation and Detection of Magnetic Nanoparticles for Diagnostic Applications.” Handbook of Biosensors and Biochips. Edited by R. Marks, et al. John Wiley & Sons, Ltd. © 2007.

[3] C.C. Ooi, R. M. Erb, B. B. Yellen, ***Journal of Applied Physics*** 103, 07E910 2008.

[4] R. M. Erb, et. al. ***Nature***. *February 2009.*

[5] M. D. Krebs*, R. M. Erb*, et. al. *In Review at* ***NanoLetters***. **Co-first authors*

[6] R. M. Erb, et. al. *In Submission to* ***Nature Materials***.

[7] B.B. Yellen, R. M. Erb, et. al. ***Lab on a Chip****,* 7, 1681 - 1688, 2007.

[8] B. Yellen, R. M. Erb, et. al. ***IEEE Transactions on Magnetics*** 42-10, 3548-3553, 2006.

[9] R. M. Erb, et. al. ***Journal of Applied Physics***, 103, 063916-5, 2008.

[10] R. M. Erb, B. B. Yellen. ***Journal of Applied Physics*** 103, 07A412, 2008.

[11] R. M. Erb, et. al. *In Submission to* ***Langmuir***.

[12] R. M. Erb, B. B. Yellen. ***IEEE Transactions on Magnetics*** 42-10, October 2006: 3554-3556.

[13] R. M. Erb, et. al. In Submission to **Applied Physics Letters**.