Contract No:

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Patterning of magneto-optical nanomaterials

Project highlight. Developed a versatile and automatic mesoscale patterning technology that provide precise and consistent control and special arrangement of functional nanomaterials.

Awards and Recognition

- 2020 Top Ten Winner: "Grace", SNAP SRS Competition in Science as Art
- 2020 Top Ten Winner: "Metamorphosis", SNAP SRS Competition in Science as Art
- 2020 Top Ten Winner: "Assembly", SNAP SRS Competition in Science as Art

Intellectual Property Review

This report has been reviewed by SRNL Legal Counsel for intellectual property considerations and is approved to be publicly published in its current form.

SRNL Legal Signature

Signature **Date**

Patterning of magneto-optical nanomaterials

Project Team: Simona Hunyadi Murph (PI), Henry Sessions, Tyler Guin, and Ray Belliveau

Subcontractor: Applied Research Center

Project Type: Seedling

Project Start Date: October 1, 2019
Project End Date: September 30, 2020

Patterning of colloidal particles in precisely organized architectures has attracted intense research interest for decades. This is due to their potential applications in flexible electronics, magnetic and optical devices, sensors, biotechnology, communications, etc. However, creation of mesoscale assemblies at commercial scale received less attention. The mesoscale systems reside between the micro- and macroscopic scales, with length dimensions from ≈ 100um to 5mm. One way to create mesoscale materials is to leverage decades of experimental and theoretical research in nanomaterials field that allows us to precisely create and control the placement of nanoscale materials. We developed a versatile and automatic mesoscale patterning technology that provide precise and consistent control and special arrangement of functional nanomaterials. The versatility of the strategy is demonstrated by patterning nanoparticles with different dimensions, shapes and compositions, tethered with various functionalities and subjected to different external stimuli. Nanomaterials were created via the patent pending automated flow-throughput domain process (AFTDP), aka nano-additive manufacturing approach, recently developed by us, based on a unique small-scale fluidics concept, that enables a uniform reaction environment for production of high-quality materials in large quantities.

FY2020 Objectives

- Fabrication of novel magneto-optical nanomaterials of various sizes, shapes, and compositions via AFTDP technology
- Preparation and characterization of novel nanomaterials: mono-metallic and/or bimetallic Au/Fe/FeXOy; Au-TiO2, Au-SiO2 and various shapes: spheres, stars, rods, triangular plates, etc.
- Large scale (mesoscale) patterning.

Introduction

Patterning of colloidal particles in precisely organized architectures has attracted intense research interest for decades. This is due to their potential applications in flexible electronics, magnetic and optical devices, sensors, biotechnology, communications, etc.

The most common surface patterning techniques, including nanoimprinting, nanografting, or a combination of nanolithography techniques coupled with chemical approaches, generate micrometer and submicrometer-sized architectures. Unfortunately, these approaches either lack the required surface coverage or a specialized and costly print/stamp technology is necessary in achieving the patterning of nanoparticle arrays on surfaces. However, creation of mesoscale assemblies at commercial scale received less attention. The mesoscale systems reside between the micro- and macro-scopic scales, with length dimensions from ≈ 100um to 5mm.

One way to create mesoscale materials is to leverage decades of experimental and theoretical research in nanomaterials field that allows us to precisely create and control the placement of nanoscale materials. The key to the production of mesoscale systems is tailoring nanomaterials' chemical functionality as a way of controlling and tuning their molecular interactions and at their interfaces in ways that can be used to couple materials together to develop new capabilities and architectures.

We proposed to develop a versatile and automatic mesoscale patterning technology that will provide precise and consistent control and special arrangement of functional nanomaterials. The versatility of the strategy was demonstrated by patterning nanoparticles with different dimensions, shapes and compositions, tethered with various functionalities and subjected to different external stimuli.

Approach

Nanomaterials created via the patent pending automated flow-throughput domain process (AFTDP) recently developed by us, aka nano-additive manufacturing approach based on a unique small-scale fluidics concept, that enables a uniform reaction environment for production of high-quality materials in large quantities.

Spatial assembly and distribution of nanoparticles in various architectures was be achieved by surface functionalization/recognition, template directed self-assembly, external electric or magnetic fields, among others.

Results/Discussion

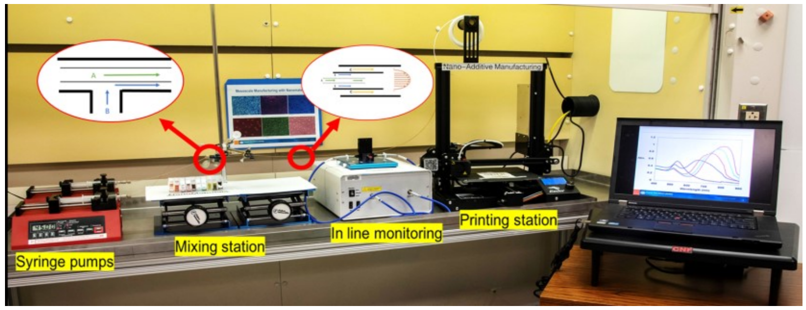

Figure 1. Automated flow-throughput domain process (AFTDP) recently developed by us, aka nano-additive manufacturing approach.

Nanomaterials of various sizes (1-100 nm), shapes (rods, spheres, triangular plates, stars, etc.) and compositions (Au/Fe/FeXOy; Au-TiO2, Au-SiO2) were prepared through a solution chemistry, through the reduction of molecular precursors in the presence/absence of surfactants, and capping agents(**Figure 1**). The ligands on the surface are used to stabilize the NPs and change the surface energy at certain facets through preferential adsorption to achieve shape control. The reduction rates of the metal precursors, reductant-to-precursor ratio, ligands and strength of reductant all were used to manipulate the final product which affect the optical and physical properties. By automatically varying the amount, volumetric flow rates, timing, location, size of the capillaries/tubings, etc. of the injected reagents, highly reliable and uniform nanomaterials were produced. Continuous operation of the system allows production of nanomaterials in large quantities. Once produced, nanomaterials were deposited in various patterns generating two dimensional printed surfaces.

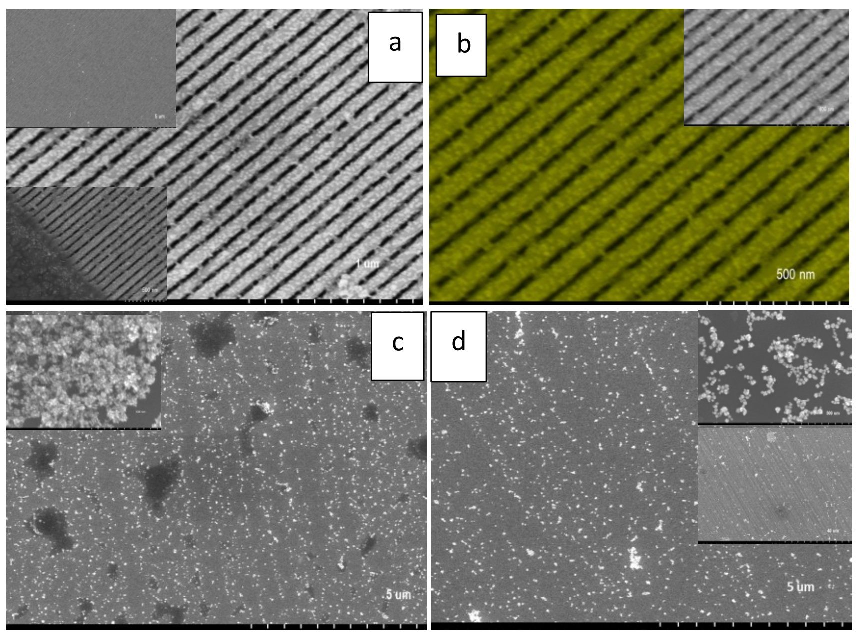

Figure 2. Mesoscale assembles nanostructures (a, b) gold nanostructures into parallel line patterns on the surface of gold /silver surfaces or (c, d) Au-FeOx on patterned magnetic medium.

A number of different support compositions were used for deposition, including quartz, gold/silver supports, stainless steel, copper, longitudinal and transverse magnetic media. The mesoscale surfaces were characterized through a series of analytical tools to elucidate materials physico-chemical properties. This includes electron microscopy, spectroscopy, UV-Vis spectroscopy, dynamic light scattering, PALS surface charge, etc. Data shows that the materials retain their properties upon additive manufacturing in 2D patterns.

Depending on the Nps properties (concentration, size, shape, surface functionalization, etc.) different assemblies and patterns were produced. Factors affecting the magnetic and non-magnetic nanostructure assembly include nanoparticle's properties, e.g. magnetic susceptibility, surface chemistry, size, etc., media magnetic gradient strength, solvent ionic strength, factors in preserving self-assembled structure, wetting properties of the solvent, possibly solvent volatility, surface tension can disturb assembled nanoparticles.

FY2020 Accomplishments

- Mesoscale Printing: Nanomaterials produced by our automated flow-throughput domain process (AFTDP) recently developed by us, aka nano-additive manufacturing approach were printed on various surfaces through reliable surface functionalization/ patterning approaches.
- Assemblies and patterns dependent on the Nps properties (concentration, size, shape, surface functionalization, etc.
- One patent application was filled with the US Patent and Trademark Office.
- One manuscript in preparation.
- Hired one postdoc researcher.

Future Directions

A multifactorial experimental design will be used to (i) explore the correlation between the processing parameters that govern both production and 3D nano-additive printing of advanced nanomaterials, and (ii) elucidate the fundamental understanding of the process-structure-property relationships of these technologies.

FY 2020 Peer-reviewed/Non-peer reviewed Publications

- Manuscripts in preparation

Presentations

- Honorable Paul Dabbar, Undersecretary for Science

Acronyms

ARC – Applied Research Center
SRNL – Savannah River National Laboratory
AM - Additive Manufacturing
3D – Three Dimensional
4D – Four dimensional
UAVs - Unmanned Aerial Vehicles
SEM – Scanning Electron Microscopy
EDS – Energy Dispersive X-ray Spectroscopy
ICP-MS - Inductively coupled plasma mass spectrometry
UV-Vis – ultraviolet - visible
ETEBA - Energy, Technology and Environmental Business Association

Intellectual Property

- System and Methods for Manufacturing Nano-Scale Materials

Total Number of Post-Doctoral Researchers

1 - Ray Bellliveau (SRNL)