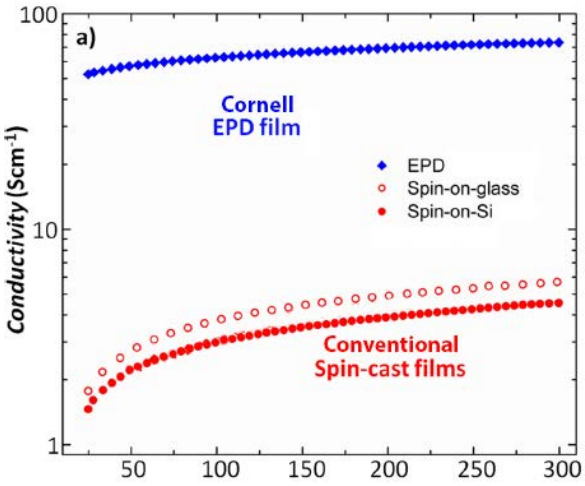
Room Temperature Assembly of Conductive Nanoparticle Based Thin-Films

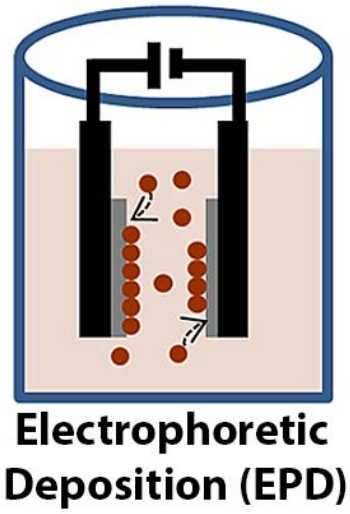
Invention Summary

We present a robust room-temperature method for assembling colloidal nanoparticles into conductive thin films. Our nanoparticle-based thin films have orders of magnitude higher conductivity when compared to spin cast analogs.

Technology Overview

There is a growing demand for solution-based processes for manufacturing electronics. Solution based methods offer a new route to fabricate large-area flexible electronic devices at substantially lower costs.





Inventors:
Obafemi Otelaja
Richard Robinson

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Licensing Contact:
Carolyn Theodore
(607) 254-4514
cat42@cornell.edu

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Our room-temperature method uses 'Electrophoric Deposition' (EPD) to uniformly coat a surface with nanoparticles from a colloidal solution. Traditional thermal treatment often results in undesired phase change or sintering of the nanoparticles. As an alternative, we have developed a gentle chemical-based post-treatment method. Our chemical treatment, using ammonium sulfide, facilitates removal of surface ligands and promotes formation of chemical connections between the nanoparticles. This treatment not only maintains the original nanoparticle size distribution but it is gentle enough to preclude any unwanted phase changes.

Furthermore, in our studies using copper sulfide nanoparticles, this process transforms the as-deposited electrically insulating films into highly conducting films with conductivities on par with many bulk copper sulfide films. When compared to traditional methods such as spin coating, we see an order of magnitude enhancements in conductivity using our electrophoretic deposition (EPD) method (~75 S/cm vs ~5.7 S/cm). This dramatic enhancement in conductivity observed in the EPD generated films is due to better particle packing combined with enhanced inter-particle coupling. Our ammonium sulfide based chemical treatment results in 1-4 orders of magnitude higher electron hole mobilities compared with other methods involving heat treatment. Overall, our room-temperature processing method presents a facile approach to obtaining (p-type) conducting films.

Potential Applications

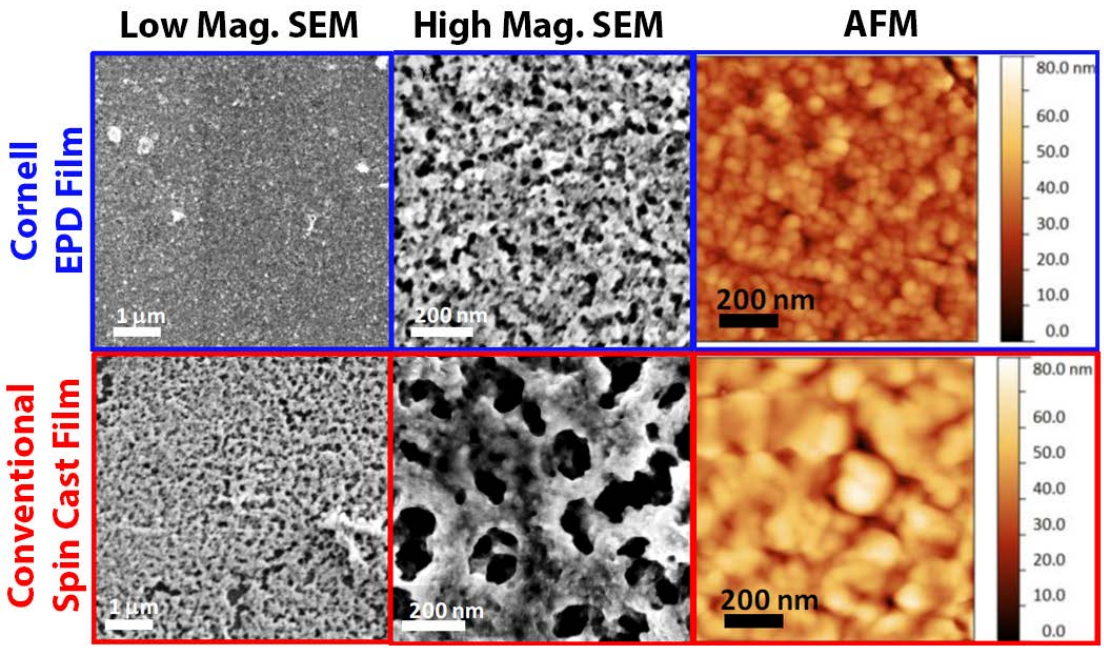
- Low-cost fabrication of flexible and large area electronic devices
- Suitable for making electrodes for an 'all-nanoparticle' based device
- Applicable toward obtaining 'p-type' conducting films
- Potential for solar cell fabrication

Advantages

- Conductivities comparable to bulk copper sulfide
- Several orders of magnitude higher hole mobility and conductivity compared to fabrication methods based on heat treatment
- Highly scalable solution-based process
- Cost effective room temperature synthesis
- No heat treatment required

Publications

- O.O. Otelaja, DH Ha, T. Ly, H. Zhang, R. D. Robinson. "Highly Conductive $Cu_{2-x}S$ Nanoparticle Films through Room-Temperature Processing and an Order of Magnitude Enhancement of Conductivity via Electrophoretic Deposition" *ACS Appl. Mater. Interfaces*, 2014, 6 (21), pp 18911–18920. DOI: 10.1021/am504785f
- Richard Robinson, Obafemi Otelaja. "Enhanced Conductivity Metal-Chalcogenide Films Via Post Electrophoretic Deposition (EPD) Treatment" US Patent Application US14/872731, Priority Date: October 2, 2014.



SEM and AFM images of Cornell's EPD (blue outlines) and conventional spin-cast (red outlines) films treated with ammonium sulfide. EPD is shown to form a tighter and more uniform film than spin-casting.