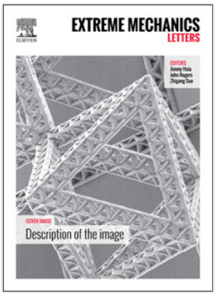
Accepted Manuscript



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PII: S2352-4316(16)30256-5
DOI: http://dx.doi.org/10.1016/j.eml.2017.02.009
Reference: EML 275

To appear in: *Extreme Mechanics Letters*

Received date: 18 November 2016

Please cite this article as: T.R. Lear, S.-H. Hyun, J.W. Boley, E.L. White, D.H. Thompson, R.K. Kramer, Liquid metal particle popping: Macroscale to nanoscale, *Extreme Mechanics Letters* (2017), http://dx.doi.org/10.1016/j.eml.2017.02.009

Liquid Metal Particle Popping: Macroscale to Nanoscale

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ABSTRACT

Liquid metal nanoparticles can be used to produce stretchable electronic devices. Understanding the mechanical properties of liquid metal nanoparticles is crucial to optimizing their use in various applications, especially printing of flexible, stretchable electronics. Smaller nanoparticles are desired for high-resolution printing and compatibility with existing scalable manufacturing methods; however, they contain less liquid metal and are more difficult to rupture than larger particles, making them less desirable for post-processing functionality. This study investigates the mechanics of liquid metal particle rupture as a function of particle size. We employ compression of particle films to characterize the composition of the particle core and derive a minimum particle size required to achieve sintering and subsequent conductance. We further derive the force required to rupture a single particle and validate the results by rupturing individual nanoparticles using atomic force microscopy. Finally, we relate the liquid metal nanoparticles to isotropically-elastic thin-shell microspheres to approximate the particle shell stiffness. An increased understanding of the behavior of liquid metal nanoparticles during rupture reveals limitations of current manufacturing processes and paves the way for the next generation of scalable mass-producible soft electronics using additive manufacturing technologies.

Keywords: Gallium indium alloy, liquid metal, nanoparticles, atomic force microscopy, particle rupture, nanoindentation

INTRODUCTION

Liquid metals offer new opportunities for flexible, stretchable, and shape changing electrical components [1-10]. Effective techniques to process liquid metal have been demonstrated and include injection into microchannels [1, 3], imprinting [11], masked deposition [12], and extrusion [13-15]. Although it is possible to manipulate liquid metals at submillimeter length scales, these techniques are greatly inhibited by the spontaneous formation of a thin metal oxide layer on the liquid metal surface in the presence of oxygen. This metal oxide is the mechanism behind the unique capability of liquid metals to form free-standing structures [14, 16], but also produces a high surface tension that makes them incompatible with scalable liquid processing techniques [16, 17], such as inkjet printing. Inkjet printing is desirable due to its capacity to create high resolution patterned devices while remaining a high-yield process. The ability to inkjet print any liquid for a particular application is indicated by the Ohnesorge number, which relates the viscous forces to inertial and surface tension forces, and liquid metal has been shown to be outside the range of printability [18].