Laser Ablation Synthesis of Energetic Graphitic Coated Aluminum Nanoparticles

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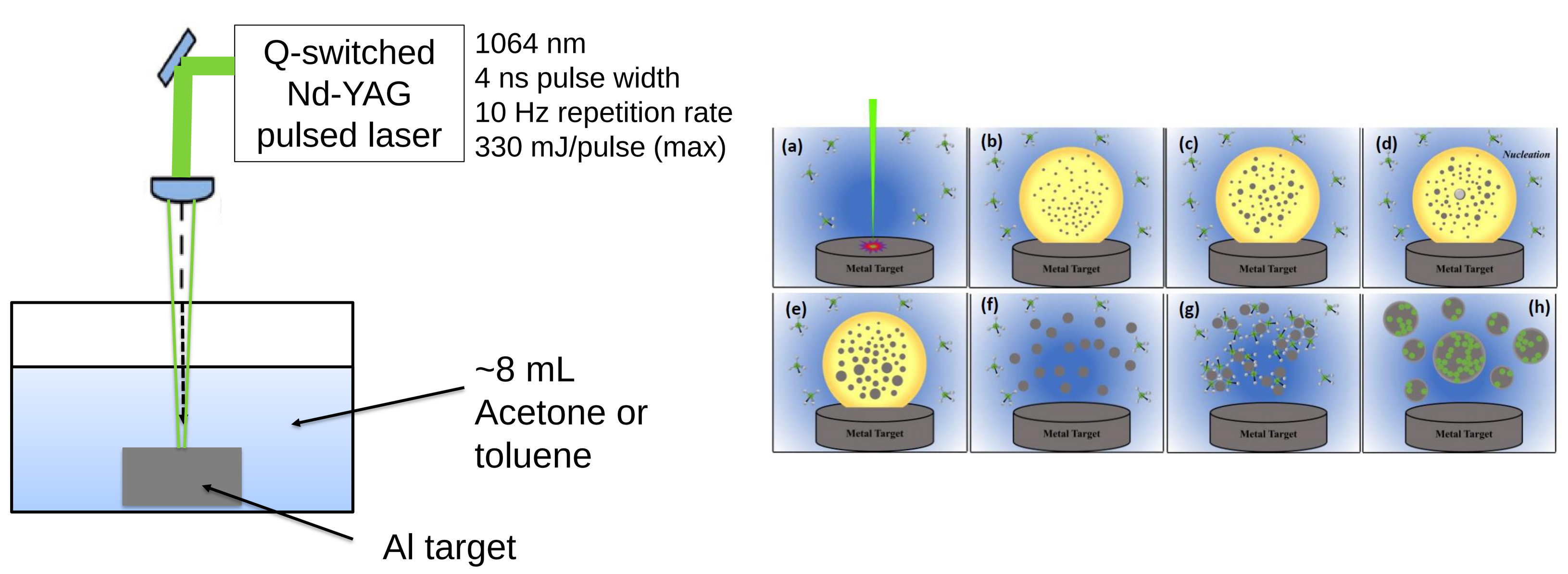
Abstract

Nanomaterials have gained widespread attention from an array of scientists and engineers for their unique physical and chemical properties that are believed to be a product of their high surface area to volume ratios, thus making them favorable for a wide variety of engineering applications. Specifically, here aluminum (Al) nanoparticles (NPs) are investigated for their energetic behaviors suitable for solid-state propellants. However, it is challenging and unsafe to preserve pristine Al NPs without any unwanted surface oxidation in ambient conditions, which in turn passivates and retards their energetic activities. To address these challenges, this poster presents a research initiative in collaboration with the US Army Research Lab (ARL) to synthesize graphitic-coated Al NPs as alternative and enhanced energetic materials via laser ablation in organic solutions.

Introduction and Motivation

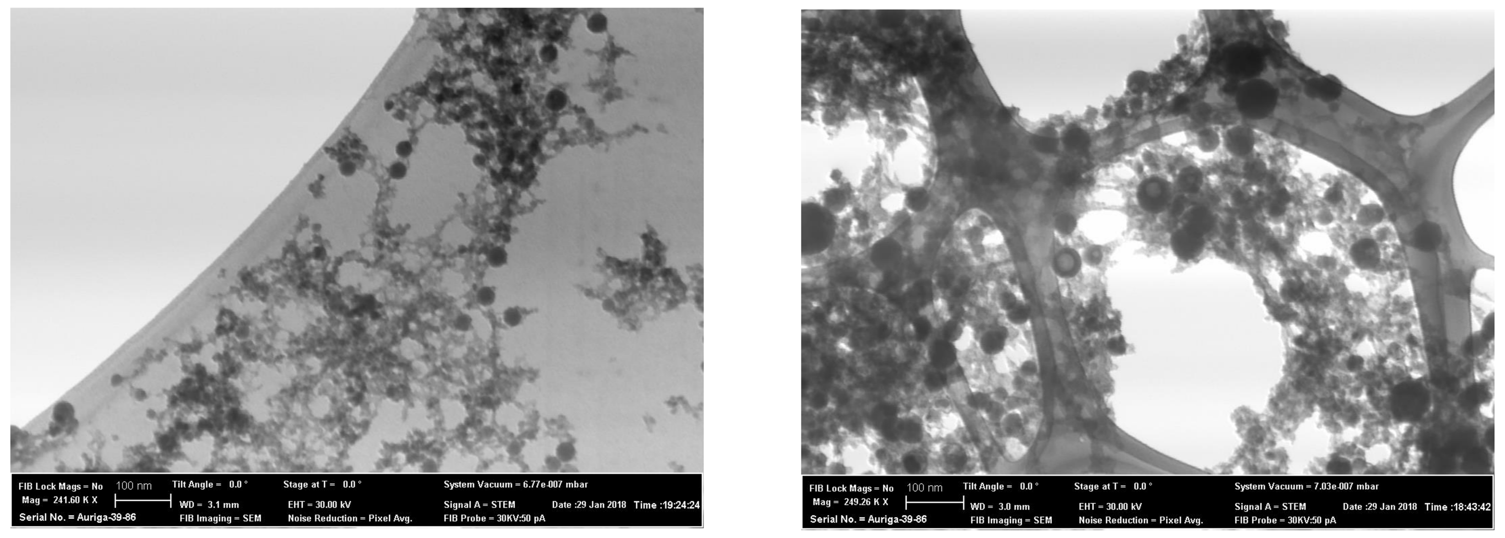
- Al has large enthalpy of combustion (~1675 kJ/mol for bulk; ~2324 kJ/mol for single atom) → smaller sizes equals more energy
- A facile technique is proposed to synthesize Al NPs encapsulated in graphitic shells to prevent any unwanted surface oxidation.
- Laser ablation synthesis in solution (LASiS) offers a green, facile, and inexpensive way to synthesize these graphitic-Al shell-core NPs while offering a way to manipulate desired NP characteristics such as composition and size distribution.
- It was hypothesized that the carbon coatings would not only protect the Al NPs from surface oxidation but also enhance performance in such ways that it would retard the particle aggregation rates and allow for fine-tuning of energetic behaviors.

LASiS Setup



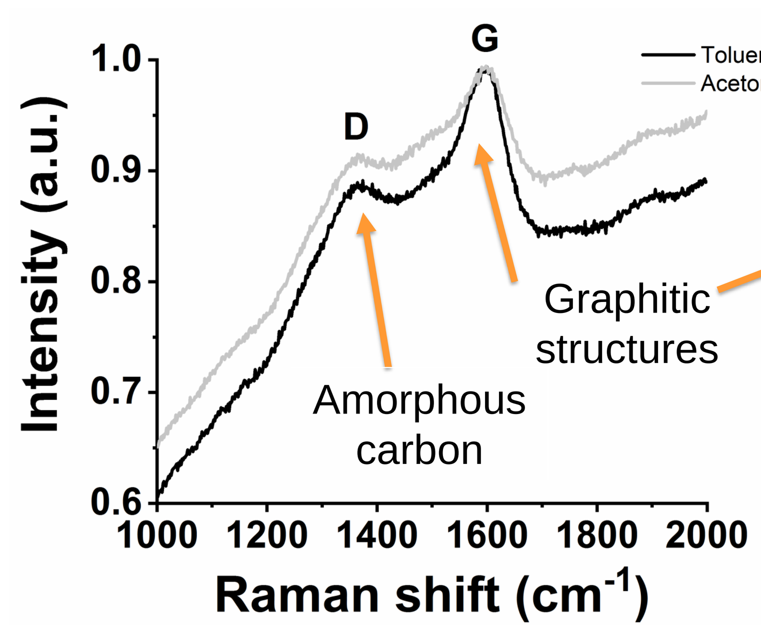
Results

Effect of Solution

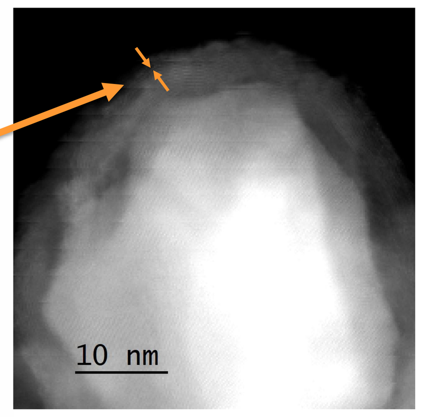


Scanning Transmission Electron Microscope (STEM) images of samples prepared in acetone (left) and toluene (right). Ablation occurred for 4 min at a laser fluence of 2.6 J/cm^2. Both show nanoparticles in a carbon matrix. The NPs in toluene appear to be larger than those in acetone.

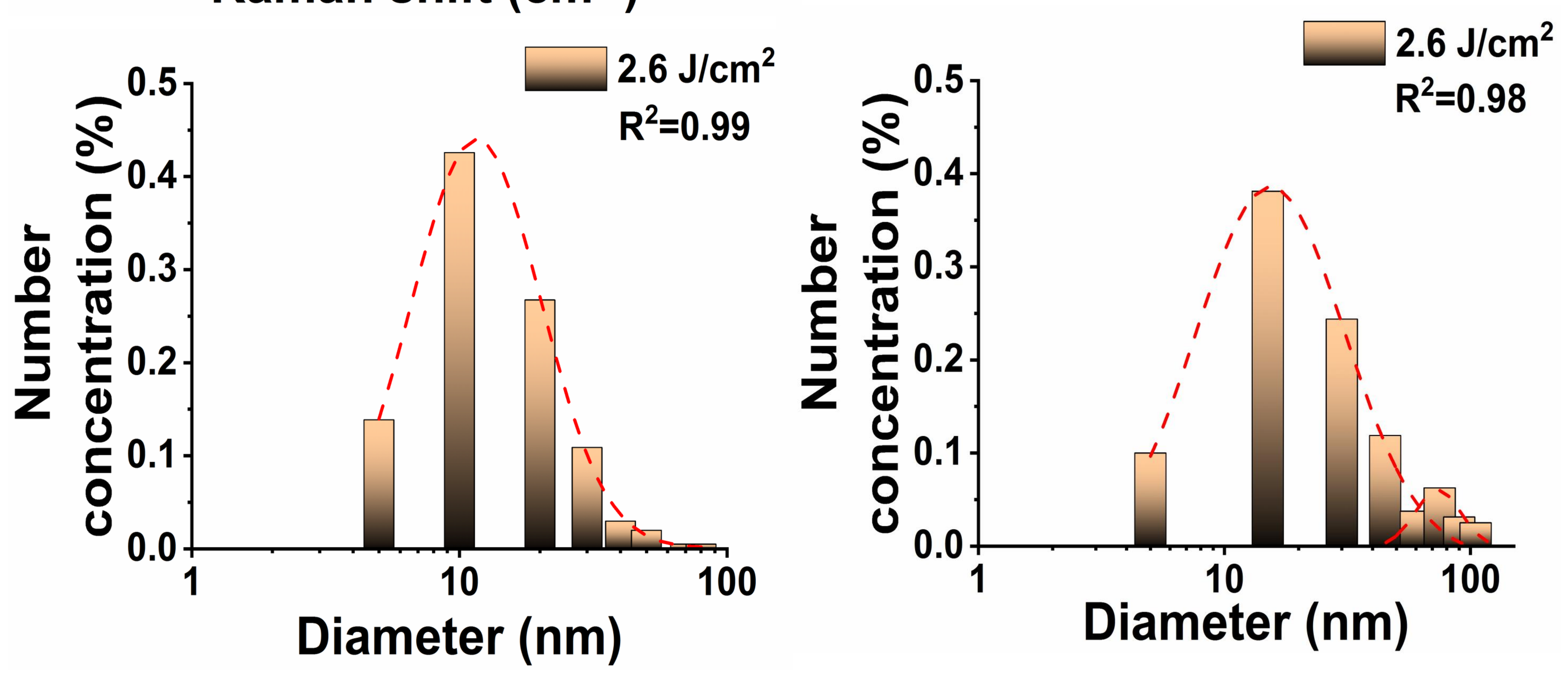
Results



- Both show D- and G-band at ~1375 and 1585 cm^{-1} respectively

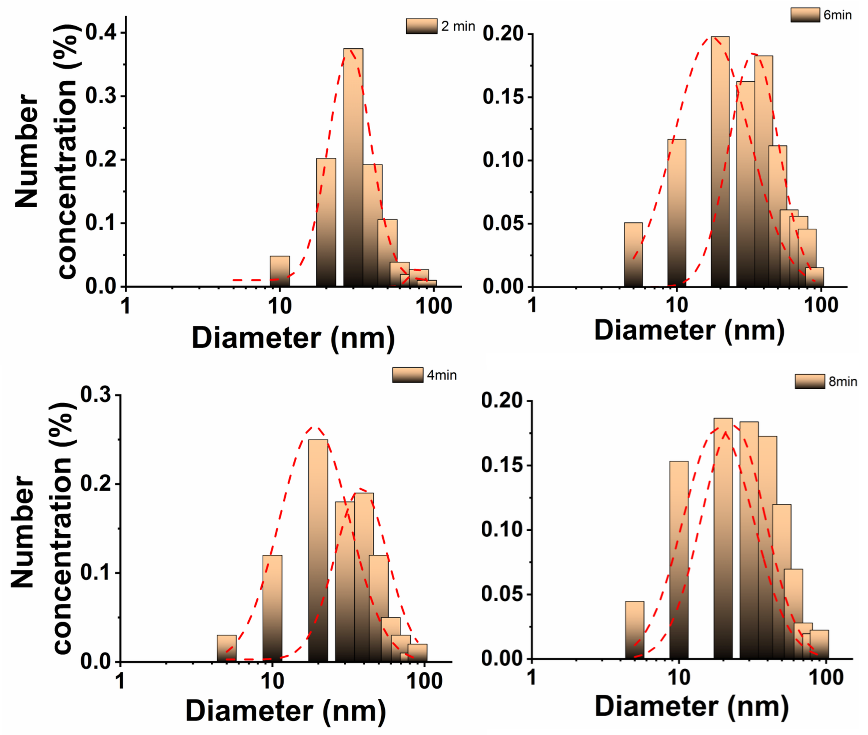


High resolution TEM (HRTEM) showing the presence of graphitic coating.



Particle size distributions for acetone (left) and toluene (right). Toluene exhibits bimodal distribution.

Effect of Time

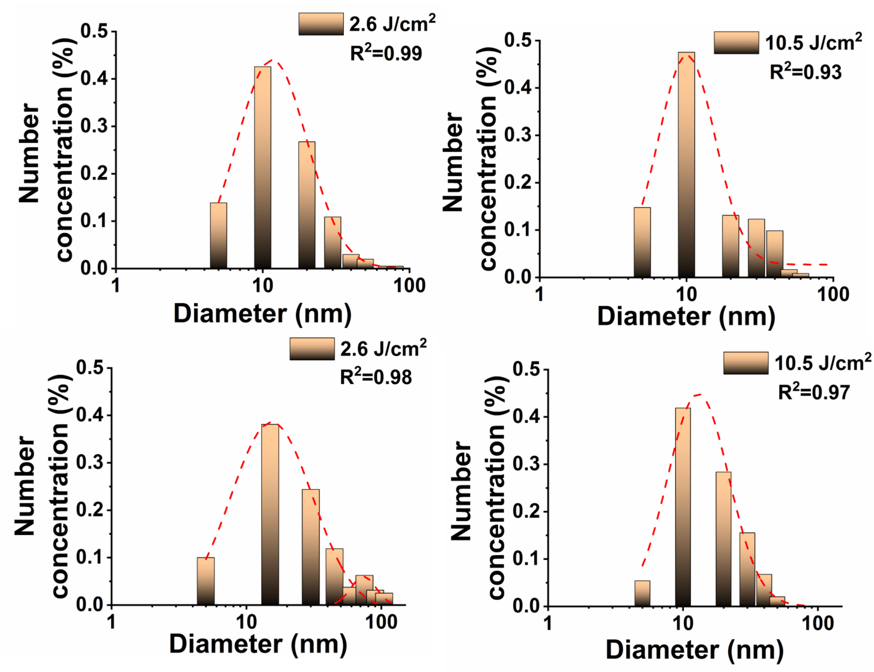


Particle size distributions for ablation in toluene for 2 min (top left), 4 min (top right), 6 min (bottom left), and 8 min (bottom right).

- Nearly unimodal narrow spread at 2 min and a unimodal wide spread at 8 min
- 4 min and 6 min exhibit some bimodal behaviors
- Increasing ablation time decreases the bimodal peak differences and increases overall particle size

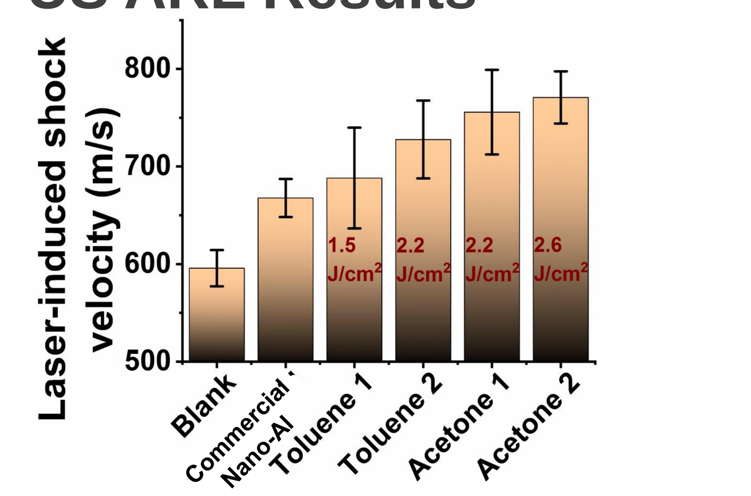
Results

Effect of Laser Fluence

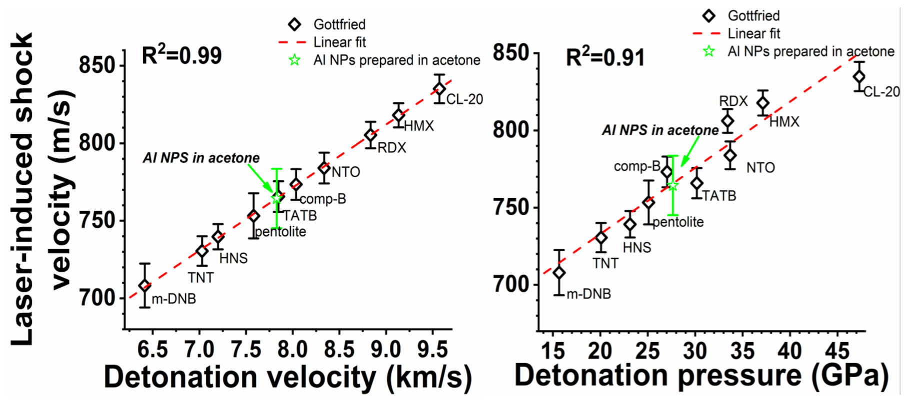


- Particle size distributions for ablation in acetone (top) and toluene (bottom) for two different fluences.
- Increasing fluence decreases modal sizes and standard deviations
- Higher vapor pressure of acetone (32 kPa) vs toluene (3.8 kPa) results in earlier solvent and carbon coating pyrolysis for acetone

US ARL Results



Laser-induced air shock from energetic materials (LASEM) results for toluene and acetone at different laser fluences.



Detonation velocity and pressure for graphitic-coated Al NPs prepared in acetone compared to various other explosive materials. Synthesized samples show higher LASEM activity than well-known explosive materials such as TNT.

Conclusion

- Samples prepared in acetone at 2.2 and 2.6 J/cm^2 produce highest shock velocities (>750 m/s)
- Compared to commercial Al nanopowders, graphitic-coated Al NPs indicate higher velocities that can be attributed to the shells retarding the surface oxidation
- Acetone's higher vapor pressure than toluene → earlier pyrolysis → earlier shell formation → slower particle aggregation → smaller particles → faster reactivity
- NPs synthesized in toluene exhibit exothermic properties while those in acetone exhibit explosive properties
- Varying solvent, time, and laser fluence allows for fine-tuning of the NP properties

Acknowledgements

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References: S.A. Davari, J. L. Gottfried, E. L. Ribeiro, G. Duscher, D. Mukherjee,**; In Preparation (2018)**; S. Davari, S. Hu, D. Mukherjee, **Talanta, 164 (2017)**; S. Hu, M. Tian, E. L. Ribeiro, G. Duscher, D. Mukherjee, **J. Power Sources, 306 (2016)**; S. Hu, G. Goenaga, C. Melton, T. A. Zawodzinski, D. Mukherjee, **Appl. Catal. B, 182 (2016)**; S. Hu, C. Melton, D. Mukherjee, **PCCP, 16 (2014)**; J. L. Gottfried, **Prop., Expl., Pyrotech., 40 (2015)**; J. L. Gottfried, **PCCP, 16 (2014).**

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