Northeastern University
College of Professional Studies

Russian Academy of Science
Moscow

2014 Fall Faculty Conference.

Nadezda G. Berezkina, et al. ***Talrose Institute for Energy Problems of Chemical Physics***, *Russian Academy of Science, Moscow, Russia*
G. Fred Lopez - ***College of Professional Studies***, *Northeastern University, Boston,*

ADVANCED RESEARCH IN NANOTECHNOLOGY:

Synthesis and Characterization of Aluminum Nanoparticles with Customized Coatings Manufactured via the Flow-Levitation Method

NANO 2014

Background

The high **reactivity and explosiveness** of aluminum nanoparticles are attractive characteristics for **energetic** technologic **applications** that can fulfill civilian and/or military needs. However, the extremely high **chemical surface activity** in conjunction with **agglomeration susceptibility** present a serious manufacturing challenge during synthesis of aluminum nanoparticles which lead to undesirable **pyrophoric effects and adsorption of environmental species**.

This technical issue can be resolved by applying **customized chemical coatings** on the surface of the aluminum nanoparticles before metal-to-metal bonds are formed.

Among the existing techniques for **deposition of nano-scaled customized coatings**, the Guen-Miller Flow-Levitation (FL) method proves to posses the needed versatility for *in-situ* deposition of coatings that allow proper control of agglomeration and chemical reactivity of Aluminum nanoparticles.

Abstract

This is a detailed study and characterization of aluminum nanoparticles that have been **coated with customized inorganic, organic and element-organic materials** in order to prevent undesirable agglomeration and surface activity between particles. The study focuses on **Aluminum nanoparticles with oxide, (oxy)nitride, organic, silicon- and fluorine-organic coatings, and aluminum oxide particles**. Characterization of nanoparticles was performed using transmission **(TEM)** and scanning **(SEM)** electron microscopy methods, electron diffraction analysis **(EDA),** energy-dispersion spectroscopy **(EDS),** electron spectroscopy for chemical analysis **(ESCA)** and X-Ray diffraction analysis **(XRD).** Specific surface areas were measured using the **BET** technique by nitrogen adsorption. Composition of volatile layers on the particles was studied using temperature-programmed desorption method with mass-spectral desorption products analysis **(TPD).**

References

- **M. I. Lerner, N. V. Svarovskaya, S. G. Psakhie, O. V. Bakina,** Production Technology, Characteristics, and Some Applications of Electric Explosion Nanopowders of Metals, Nanotechnol. Russ. 4 (2009) 741–757.
- **Y.-S. Kwon, A.A. Gromov, A.P. Ilyin,** Reactivity of superfine aluminum powders stabilized by aluminum diboride, Combust. Flame 131 (2002) 349-352.
- **Yu.A. Kotov, I.V. Beketov, A.I. Medvedev, O.R. Timoshenkova,** Synthesizing Aluminum Nanoparticles in an Oxide Shell, Nanotechnol. Russ. 4 (2009) 354–358.
- **A. E. Ermakov, M. A. Uimin, E. S. Lokteva, A. A. Mysik, S. A. Kachevskii, A. O. Turakulova, V. S. Gaviko, and V. V. Lunin,** The Synthesis, Structure, and Properties of Carbon-Containing Nanocomposites Based on Nickel, Palladium, and Iron, Russ. J. Phys. Chem. A 83(7) (2009) 1187–1193.
- **A.N. Jigatch, I.O. Leipunsky, M.L. Kuskov, P.A. Pshechenkov, N.G. Berezkina, M.N. Laritchev, V.G. Krasovsky,** Synthesis of coatings on ultra-fine aluminum particles surface, Russ. J. Phys. Chem. B 21(4) (2002) 72–78.
- **M.N. Larichev, O.O. Laricheva, I.O. Leipunsky, P.A. Pshechenkov, A.N. Jigatch, M.L. Kuskov, V.S. Sedoi,** New "reactive" coatings for surface passivation of nanosize Al particles aimed for energetic usage, Russ. J. Phys. Chem. B 25(10) (2006) 72-79.
- **A.N. Zhigach, N.G. Berezkina, I.O. Leipunskii, M.L. Kuskov, E.S. Zotova, B.V. Kudrov, L.A. Novokshonova, - O.I. Kudinova, V.V. Artemov, O.M. Zhigalina,** Production of nanosized aluminum powders and their application as fillers for composite materials based on ultrahigh molecular polyethylene (UHMPE), Bull. Russ. Acad. Sci.: Phys. 75 (2011) 1488–1494.
- **M.Ya. Guen, A.V. Miller,** A technique for synthesis of metal aerosols, USSR Patent 814432, 1961.
- **M.Ya. Guen, A.V. Miller,** Flow-levitation method for synthesis of ultrafine metal powders, Phys., Chem. Mech. Surf. 2 (1983) 150-154.
- **A.N. Jigatch, I.O. Leipunsky, M.L. Kuskov, T.M. Verzhbitskaya,** Influence of aluminum particle sizes on their surface chemical characteristics, investigated by probe gas temperature programmed desorption mass spectrometry, Rapid Commun. Mass Spectrom. 13 (1999) 2109-2117.

Objective of this research: Develop and perfect a technique for ***in-situ*** **deposition of customized inorganic and organic coatings** on aluminum nanoparticles during synthesis via the **Guen-Miller Flow Levitation (FL) method** in order to prevent particle agglomeration and suppress high chemical activity.

The Guen-Miller FL method: **invented in Russia** and **unknown in the US**. drop of molten material levitates in a high-frequency electromagnetic field. Vapors then condense homogeneously into nanoparticles in an inert carrier gas flow.

Underlying principles and chemical reaction for coatings formation on the surface of Al nanoparticles

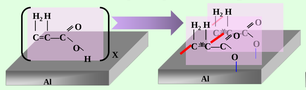
Inorganic coatings:

Formation of Al oxide coatings:
$$2Al_s + 3O_2 \rightarrow (Al_2O_3)_s$$

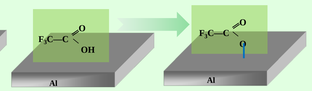
Formation of Al nitride coatings:
$$2Al_s + 2NH_3 \rightarrow 2AlN + 3H_2$$

Organic coatings:

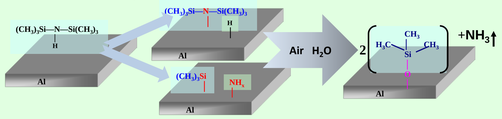
Formation of Poly-acrylic coatings



Formation of Tri-fluorine-organic coatings

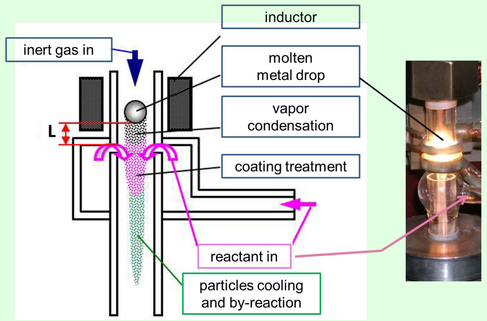


Formation of Trimethyldisiloxane coatings



Technique and characterization

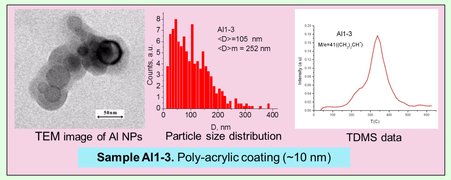
Experimental coating deposition technique on Al nanoparticles



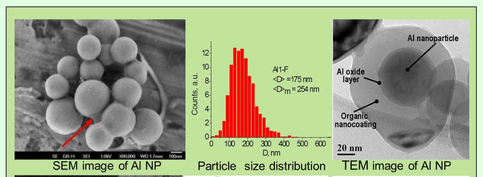
Key parameters for proper coating deposition:

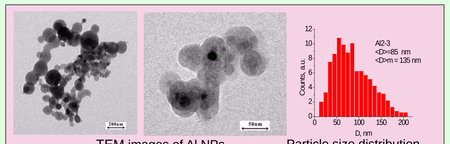
1) Distance **L** must be carefully selected to ensure the **proper chemical reaction** and achieve the required properties of the coating.
2) Proper concentration of reactive gas is needed so that the reaction is fast enough to form coating ***before the collisions*** that eventually occur among the forming nano-particles.

Sample Results - Organic nano-scaled coatings

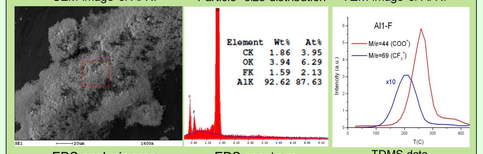


Sample Al1-3. Poly-acrylic coating (~10 nm)



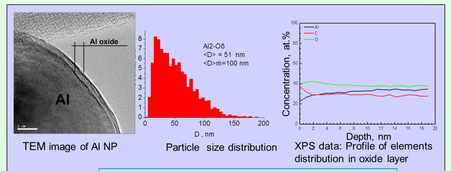


Sample Al2-3. Poly-acrylic coating (4÷28 nm)

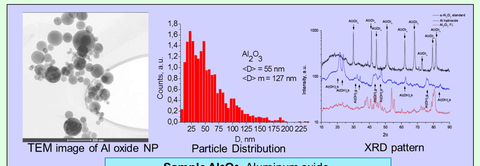


Sample Al1-F. Fluoro-organic coating

Sample Results - Inorganic nano-scaled coatings



Sample Al2-Ox. "Thin" layer of oxide coating (≤10 nm) Oxidation in "hot zone"



Sample Al_2O_3. Aluminum oxide. High-temperature (~1500 K) metal oxidation in Ar-O_2

Conclusions

- The Guen-Miller **FL-method** in conjunction with **nano-scaled surface chemical modification of nascent nanoparticles** constitute a powerful and versatile method to control **physicochemical properties** of metal particles.
- The characteristic **high reactivity** and undesirable **agglomeratio**n of **aluminum nanoparticles** can be controlled by the deposition of nano-scaled organic and/or inorganic coatings on the surface of the particles.
- Coating uniformity and thickness depend on proper **concentration of reagent gas** and its **injection distance** downstream the nascent nanoparticles during synthesis.
- Coating deposition is highly sensitive to the **temperature of reaction** which in turn is dependent on the **operation regime** of the manufacturing apparatus, i,e: inhert gas flow rate and pressure, metal evaporation rate, type of carrier gas and heat of reaction.
- Coated particles present a wide variety of morphologies depending on the coating process and material. Shapes observed vary from perfectly spherical to "pea-like" shapes, to corrugated reliefs resembling "brain-shaped" morphology.
- Aluminum particles with organic and silicon-organic coatings possess strong hydrophobic properties.

Relevancy Across Disciplines

Methods to control physical properties of nanomaterials via nano-scaled customized coating have extensive, in medicine, engineering and science. In particular, aluminum coated nanoparticles have direct applicability in energetic applicatiosn such as explosives and alternative fuels production.

Acknowledgements

1. ***To the Talrose Institute for Energy Problems of Chemical Physics,*** *of the Russian Academy of Science for securing funds from the* ***RFBR*** **(project #14-03-0990)** *for this research.*
2. ***To the College of Professional Studies, Northeastern University*** *for providing funds to author F. Lopez for a trip to Moscow, Russian Federation in order to present this research in the International NANO 2014 Conference.*