ARMY RESEARCH LABORATORY

# Nanostructured Superhydrophobic Surfaces for Nanoeducation and Science, Technology, Engineering, and Mathematics (STEM) Outreach

**by Abby L West, Travis M Tumlin, Alexis M Fakner, and Mark H Griep**

**ARL-TN-0660** **February 2015**

**Approved for public release; distribution is unlimited.**

## NOTICES

### Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

**Army Research Laboratory**
Aberdeen Proving Ground, MD 21005-5066

**ARL-TN-0660** **February 2015**

# Nanostructured Superhydrophobic Surfaces for Nanoeducation and Science, Technology, Engineering, and Mathematics (STEM) Outreach

**Abby L West, Travis M Tumlin, and Alexis M Fakner**
**Oak Ridge Institute for Science and Education**

**Mark H Griep**
**Weapons and Materials Research Directorate, ARL**

**Approved for public release; distribution is unlimited.**

# REPORT DOCUMENTATION PAGE

***Form Approved***
***OMB No. 0704-0188***

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
**PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

| 1. REPORT DATE *(DD-MM-YYYY)* | 2. REPORT TYPE | 3. DATES COVERED (From - To) |
|---|---|---|
| February 2015 | Final | 1 June–31 August 2014 |

| 4. TITLE AND SUBTITLE | 5a. CONTRACT NUMBER |
|---|---|
| Nanostructured Superhydrophobic Surfaces for Nanoeducation and Science, Technology, Engineering, and Mathematics (STEM) Outreach | 1120-1120-99 |
| | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| Abby L West, Travis M Tumlin, Alexis M Fakner, and Mark H Griep | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| US Army Research Laboratory<br>ATTN: RDRL-WMM-A<br>Aberdeen Proving Ground, MD 21005-5066 | ARL-TN-0660 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S) |
| | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

**12. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

,

**14. ABSTRACT**

In an effort to attract young minds to the fields of science, technology, engineering, and mathematics (STEM), a lab setup utilizing Ultra Ever Dry superhydrophobic coatings has been demonstrated. This lab, when combined with overview and discussion, introduces middle-to-high-school-level students to the science of nanotechnology. Through various demonstrations of the water-repelling ability of the coatings, students can better understand the fundamental science of how nanostructure coatings work and the application of coatings to a variety of materials. This gives students the opportunity to hypothesize how these coatings could be used in their everyday lives along with stimulating their interest in STEM-related fields. This report details background information on nanotechnology, the fundamentals of how the nanostructure coatings work, the process of coating a variety of materials, and the results of a recent demonstration.

**15. SUBJECT TERMS**

nanostructures, superhydrophobicity, STEM, nanoeducation, corrosion

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| | | | | | Mark Griep |
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | 19b. TELEPHONE NUMBER (*Include area code*) |
| Unclassified | Unclassified | Unclassified | UU | 30 | (410) 306-4953 |

**Standard Form 298 (Rev. 8/98)**
Prescribed by ANSI Std. Z39.18

# Contents

**List of Figures** **iv**

**Acknowledgments** **v**

**1. Introduction and Background** **1**

**2. Materials and Methods** **2**

2.1 Preparation of Superhydrophobic Materials....2

2.1.1 Bottom Coat Application....5

2.1.2 Top Coat Application....6

2.2 Prelab Setup....6

2.3 Lab....6

2.4 Demonstration....6

2.5 Postlab....7

**3. Results and Discussion** **7**

3.1 Prelab Setup....7

3.2 Lab....7

3.3 Demonstration....7

3.4 Postlab....7

**4. Summary and Conclusions** **8**

**5. References** **9**

**Appendix A. Prelab Questions** **11**

**Appendix B. Nanomaterials and Superhydrophobic Coatings** **13**

**Appendix C. Data Collection** **17**

**Appendix D. Postlab Questions** **19**

**Distribution List** **21**

## List of Figures

Fig. 1 Contact angles for hydrophilic, hydrophobic, and superhydrophobic materials .....1
Fig. 2 Schematic of bilayer system. .....2
Fig. 3 Industrial size solutions of UED top and bottom coat .....3
Fig. 4 Appearance of uncoated (top) and coated (bottom) plastic tray .....4
Fig. 5 Prepared solutions of UED A) bottom coat and B) top coat showing a milky, cloudy, and white translucent appearance .....5
Fig. 6 Application of bottom coat on polycarbonate tray .....5
Fig. B-1 Classification scheme for nanomaterials .....14
Fig. B-2 Scanning electron microscope (SEM) image of UED bottom coat (left) and top coat (right).....15

## Acknowledgments

The authors would like to thank Sandra Young and Matthew Kiefert for their help in organizing all of the outreach sessions, including Gains in the Education of Mathematics and Science (GEMS), Science, Technology, Engineering, and Mathematics (STEM), and Biotechnology Title 1. The authors would also like to thank Christopher Knoblauch for his help with the demonstrations.

INTENTIONALLY LEFT BLANK.

## 1. Introduction and Background

Hydrophobic coatings are very attractive for use in several applications including antiwetting, anticorrosion, antifouling, and antimicrobial technologies.[1–7] A material exhibits hydrophobic properties when water droplets on the surface have a contact angle of 90° or greater; it is considered superhydrophobic when that contact angle is increased to 120° or greater (Fig. 1).[8]

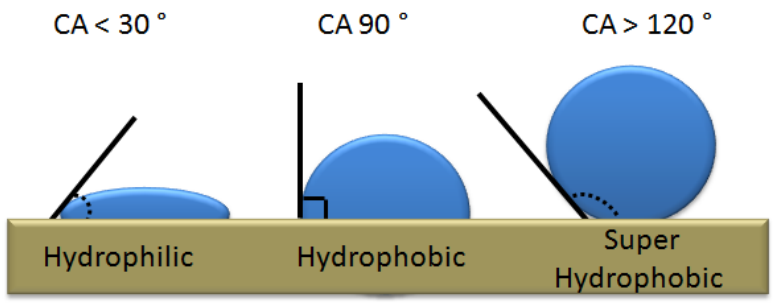


Fig. 1 Contact angles for hydrophilic, hydrophobic, and superhydrophobic materials

Producing hydrophobic or superhydrophobic materials at the nanoscale can be approached in 2 ways. The first is through chemical modification where certain nonpolar molecules such as fatty acids or oils coat a surface and repel polar molecules such as water.[1,9,10] This is why water cannot be mixed with oil. The second approach is commonly used in nature and involves covering the surface with nanostructures.[8,11,12] For example, the surface of the lotus leaf is coated with cone-shaped nanostructures that reduce the surface area that the water comes into contact with. This reduced area makes it harder for the water molecules to bind, thus making the surface hydrophobic.[13,14] Adding nanostructures to create a hydrophobic surface is also very common in industry. For example, Ultra Tech International produces a 2-part superhydrophobic coating called Ultra Ever Dry (UED). UED coatings use a nanostructure that mimics the surface of the lotus leaf by using patterns of geometric shapes that create “peaks” or “high points” to reduce surface area. This reduced surface area causes the water droplets to bead up to high contact angles

Nanotechnology is a very important module in most Science, Technology, Engineering, and Mathematics (STEM) and Gains in the Education of Mathematics and Science (GEMS) outreach programs. However, it is difficult to find a straightforward and enjoyable experiment or demonstration that both fits within time constraints and is informative to students of various education levels. Superhydrophobic coatings, specifically UED, can be used to teach students about nanotechnology.

This report describes the procedures on how UED coatings can be used to teach middle and high school students about nanotechnology. The students will see firsthand how nanostructuring a material's surface can affect the hydrophobic properties of the material by observing how even paper can become superhydrophobic when coated with UED. In addition, students will also be able to test both substrate effects and the effect of several test liquids with various water contents and viscosities on UED coatings. The results of a recent demonstration are summarized. Supplementary information for a sample lab is included as Appendixes A–D (prelab questions, nanomaterials and superhydrophobic background, data collection, and postlab questions, respectively).

## 2. Materials and Methods

### 2.1 Preparation of Superhydrophobic Materials

The coating should be sprayed onto the materials before the outreach program begins. UED coatings are comprised of 2 separate solutions. The first solution is a bottom coating that contains nanotubules. When the top coat is applied, these nanostructures create a void between the top and bottom layers. These voids contain air that acts as a barrier for the diffusion of water molecules through the surface. While water molecules are blocked from passing through the surface, smaller molecules such as air are allowed through thus making the coating breathable. This 2-step coating schematic is shown in Fig. 2.

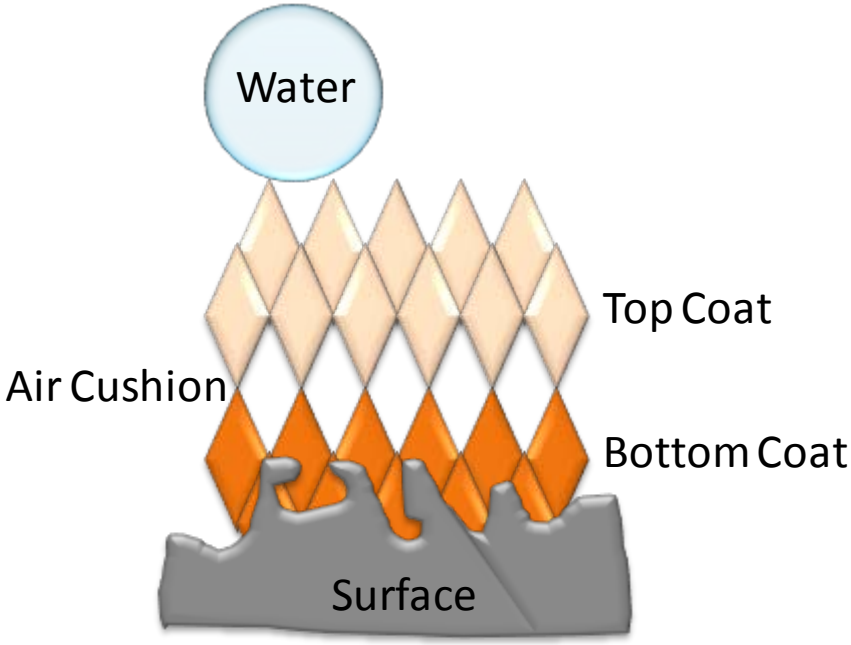


Fig. 2 Schematic of bilayer system.

UED can be purchased commercially in a variety of different volumes (Fig. 3). The basic materials required to make the coating are as follows:

- UED top coat
- UED bottom coat
- Safety goggles
- Lab coat
- Nitrile gloves
- Respirator or well-ventilated area
- Spray nozzles for both top and bottom coat
- Hair dryer or heat gun (optional)
- Materials of different innate hydrophobicities to be coated (wood, plastic, paper, cloth, metal, etc.)
- Sand paper (optional)
- Table salt
- Copper sulfate
- Water

Fig. 3 Industrial size solutions of UED top and bottom coat

Before coating the materials, there are a few precautions to follow:

- To ensure that the coating will adhere well, surface preparation should be performed prior to coating the material. Surfaces should be free of oil, grease, dust, dirt, and any other contaminants. For increased adhesion, sandpaper can be used to lightly abrade the surface.
- UED is highly flammable so extra precaution should be taken when using the solutions. Once dry, however, the coatings are not flammable.
- Because UED solutions are made with strong solvents, the application of UED should be done outside, in a well-ventilated area, or with a respirator.
- Coated materials will have a white, translucent appearance (Fig. 4) and should not be used on windows or windshields.

Fig. 4 Appearance of uncoated (top) and coated (bottom) plastic tray

### 2.1.1 Bottom Coat Application

Vigorously shake the can of the bottom coating for approximately 5 min. The solution should have a milky colored appearance (Fig. 5A). If the solution is clear, continue shaking until solution reaches a milky color. Pour the solution from the can into a dedicated sprayer. A unique sprayer is required for both the top and bottom coat. Once the sprayer is filled, shake vigorously, and apply multiple thin coats over the desired region as shown in Fig. 6. The wet thickness of the film should be between 3.0 and 5.0 mil (76 and 127 μm). The coating should be uniform; avoid overwetting the surface or pooling. Allow 15–20 min for the coating to dry. The dry thickness of the coating should be between 1.0 and 1.5 mil (25 and 38 μm). A heat gun or hair dryer on a low power setting can be used to shorten the drying time. Once the solvent has evaporated and the bottom coating is dry, the top coat can then be applied.

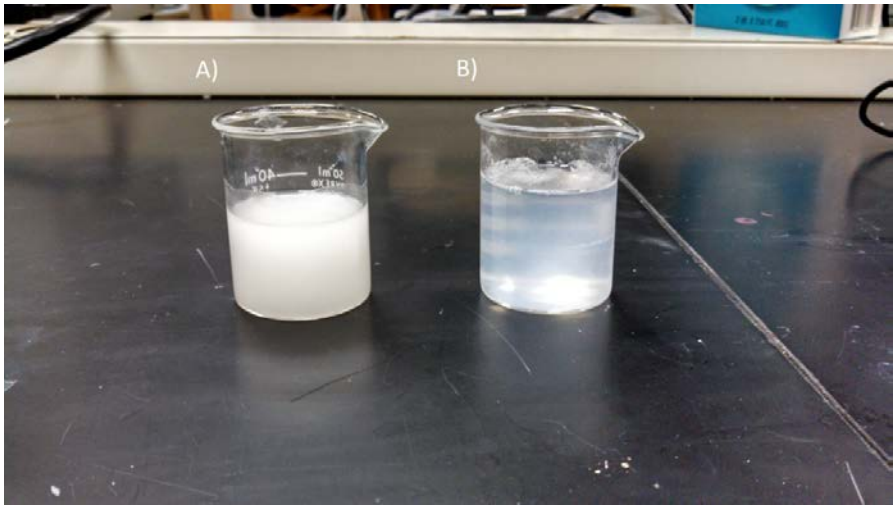


Fig. 5 Prepared solutions of UED A) bottom coat and B) top coat showing a milky, cloudy, and white translucent appearance

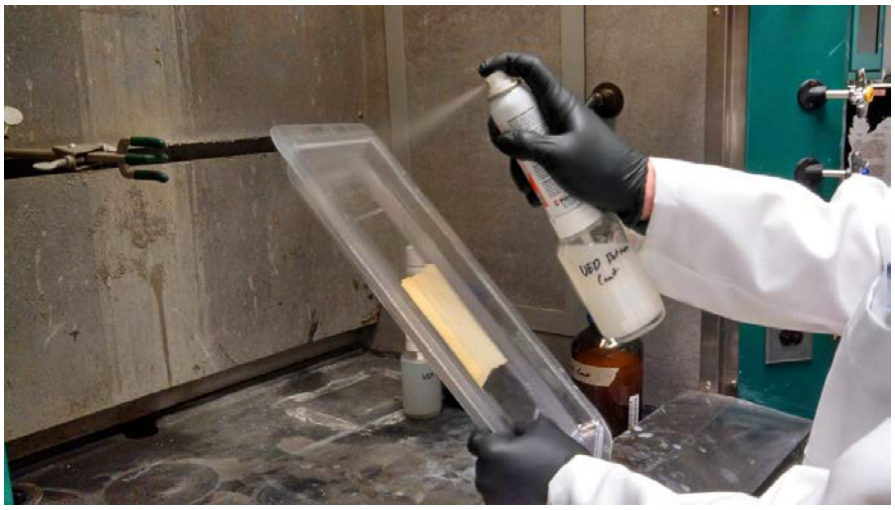

Fig. 6 Application of bottom coat on polycarbonate tray

### 2.1.2 Top Coat Application

Apply the top coat of UED following the same general procedure as the bottom coat. Use a dedicated sprayer that is only used for the top coat. Add the desired amount of top coat solution into the sprayer and shake vigorously. The solution should have the appearance shown in Fig. 5B. Apply thin, uniform films to the material. Avoid pooling and overcoating by using the same amount of top coat as the bottom coat. Shaking the sprayer a few times in between spraying can be beneficial by preventing settling of the solution. A heat gun or hair dryer can be used to dry the top coat. Allow the coating to cure fully for 2 h for best results.

## 2.2 Prelab Setup

Cover all surfaces with plastic sheeting. Set up several stations around the room with different test liquids at each station. Test liquids of varying viscosities and water content should be used, such as water, honey, concrete, paint, or oil. Divide students into groups of 3–4 with each group responsible for one set, usually placed in a bin for easy transport, of test substrates that have been coated with UED. Students will then answer several prelab questions and form a hypothesis before they begin adding various test liquids to the substrates.

## 2.3 Lab

Each group of students applies the test liquids to the coated test substrates. During testing, students wear gloves, lab coats, and safety glasses. Remind the students that more than one liquid will be tested on each substrate. If a test liquid soaks the entire substrate, it will be difficult to test further liquids. It is best to test a small section of the substrate with a small amount of test liquid and to test different sections of the substrate with each new test liquid. The students should use a number scale, for example, a scale of 1 through 5, to rank the effectiveness of the coating on each substrate against various test liquids. A rank of 1 indicates that all of the liquid stuck and 5 indicates that none of the liquid stuck to the substrate. Once the students complete one station, the groups may rotate to the next and test the liquids at that station. When completed, the students total the rankings for each substrate and test liquid.

## 2.4 Demonstration

The instructor demonstrates the coating’s ability to resist corrosion. Dissolve a small amount of copper sulfate in water by mixing. Divide the solution between 2 glass containers. Place a small square of uncoated aluminum foil inside one glass container as a control. Add a similar sized square of UED-coated aluminum foil to the other glass container. The foil should be submerged in the solution. Add a generous amount of table salt (around 1 tablespoon) to each container. Cover the containers and mix well by inverting. Students should observe the effects of the salt-water mixture on the 2 pieces of aluminum foil.

### 2.5 Postlab

Students answer several postlab questions about the effectiveness of the coating on each substrate and the type of liquid that was best/least repelled. Students should be able to indicate some limitations of the coating and ways in which it could be improved.

## 3. Results and Discussion

### 3.1 Prelab Setup

In the beginning of the lab, most students seemed to already have an understanding of what being hydrophobic means. However, students seemed to be unclear on the size scale of nanotechnology and the various applications. Students formed a hypothesis about the effect of the substrate surface on the effectiveness of the coating. The hypotheses of the students were well split between the substrate having an effect on the coating and not having an effect.

### 3.2 Lab

Students were able to apply the test liquids to the substrates and rank the hydrophobicity. Most students found that water and water-based substances were the most repelled, and liquids such as oil and paint were the least repelled. The students found that metal, paper, and wood were the best substrates to repel water, while cotton balls and leather gloves were not as repellent. Some groups of students assigned the ranking of “entirely repelled” very liberally so that many test liquids appeared to be equally repelled and many substrates had equal abilities to repel.

### 3.3 Demonstration

The copper sulfate and salt quickly started to corrode the uncoated aluminum foil. Flakes of the aluminum foil appeared in the solution and in some instances, the solution became dark in color. The coated aluminum foil showed minimal corrosion or changes in solution color. Students were able to draw similarities between the corrosion seen in this demonstration to the corrosion of the *Titanic* after hundreds of years. Even after many days in the solution, the coated aluminum foil showed only minimal deterioration.

### 3.4 Postlab

Upon completion of the lab, the students were able to answer the postlab questions and seemed to have a better understanding of the scale of nanotechnology. The students had a number of ideas for ways to improve the coating and future applications for the coating. Some suggestions for future applications include roadways for anti-icing, cell phones for antiwetting, car paint for anticorrosion, and clothing for antifouling.

## 4. Summary and Conclusions

The use of UED as a superhydrophobic coating in STEM and GEMS outreach programs was successful in teaching middle and high school students about nanotechnology. The students were engaged and found the experiments to be fun and informative. Through the completion of the experiments and demonstration, students were able to test their hypothesis and critically evaluate the commercially available product. In addition, students had hands-on experience with nanomaterials through this interactive experiment. The students gained a better understanding of the size scale of nanotechnology and potential applications.

## 5. References


1. Caschera D, Cortese B, Mezzi A, Brucale M, Ingo GM, Gigli G, Padeletti G. Ultra hydrophobic/superhydrophilic modified cotton textiles through functionalized diamond-like carbon coatings for self-cleaning applications. Langmuir. 2013 Feb 26;29:2775–2783.
2. Feng L, Zhang ZY, Mai ZH, Ma YM, Liu BQ, Jiang L, Zhu DB. A super-hydrophobic and super-oleophilic coating mesh film for the separation of oil and water. Angewandte Chemie-International Edition. 2004;43:2012–2014.
3. Fexby S, Ihre H, Buelow L, Van Alstine JA. Novel in situ polymerized coatings for hydrophobic interaction chromatography media. J Chromatogr A. 2007 Aug 17;1161:234–241.
4. Fir M, Orel B, Vuk AS, Vilcnik A, Jese R, Francetic, V. Corrosion studies and interfacial bonding of urea/poly(dimethylsiloxane) sol/gel hydrophobic coatings on AA 2024 aluminum alloy. Langmuir. 2007 May 8;23:5505–5514.
5. Larson AM, Hsu BB, Rautaray D, Haldar J, Chen JZ, Klibanov AM. Hydrophobic polycationic coatings disinfect poliovirus and rotavirus solutions. Biotechnol Bioeng. 2011 Mar;108:720-723.
6. Walker RA, Wilson K, Lee AF, Woodford J, Grassian VH, Baltrusaitis J, Rubasinghege G, Cibin G, Dent A. Preservation of York Minster historic limestone by hydrophobic surface coatings. Sci Rep. 2012;2:880.
7. Vilcnik A, Jerman I, Vuk AS, Kozelj M, Orel B, Tomsic B, Simonic B, Kovac, J. Structural properties and antibacterial effects of hydrophobic and oleophobic sol-gel coatings for cotton fabrics. Langmuir. 2009 May 19;25:5869–5880.
8. Liu YY, Chen XQ, Xin JH. Super-hydrophobic surfaces from a simple coating method: a bionic nanoengineering approach. Nanotechnology. 2006 Jul 14;17:3259–3263.
9. Ji YY, Hong YC, Lee SH, Kim SD, Kim SS. Formation of super-hydrophobic and water-repellency surface with hexamethyldisiloxane (HMDSO) coating on polyethyleneteraphtalate fiber by atmospheric pressure plasma polymerization. Surface and Coatings Technology. 2008 Aug 30; 202:5663–5667.
10. Nakajima A, Nakagawa Y, Furuta T, Sakai M, Isobe T, Matsushita S. Sliding of water droplets on smooth hydrophobic silane coatings with regular triangle hydrophilic regions. Langmuir. 2013 Jul 23;29:9269–9275.

11. Gao L, He J. Surface hydrophobic co-modification of hollow silica nanoparticles toward large-area transparent superhydrophobic coatings. J Colloid Interface Sci. 2013 Apr 15;396:152-159.

12. Ogihara H, Xie J, Okagaki J, Saji T. Simple method for preparing superhydrophobic paper: spray-deposited hydrophobic silica nanoparticle coatings exhibit high water-repellency and transparency. Langmuir. 2012 Mar 13;28:4605–4608.

13. Koch K, Ensikat HJ. The hydrophobic coatings of plant surfaces: epicuticular wax crystals and their morphologies, crystallinity and molecular self-assembly. Micron. 2008 Oct;39:759–772.

14. Zorba V, Stratakis E, Barberoglou M, Spanakis E, Tzanetakis P, Anastasiadis SH, Fotakis C. Biomimetic artificial surfaces quantitatively reproduce the water repellency of a lotus leaf. Advanced Materials. 2008 Nov 3;20:4049–4054.

# Appendix A. Prelab Questions

This appendix appears in its original form, without editorial change.

## Supplementary Information – Sample Lab

Name _____
Pre-Lab Questions

1. At what size scale is nanotechnology used?

_____
_____

2. List some examples/ideas where nanotechnology is used.

_____
_____

3. What does super hydrophobic mean?

_____
_____

4. List some uses for super hydrophobic coatings.

_____
_____

# Appendix B. Nanomaterials and Superhydrophobic Coatings

## B.1 Nanomaterials

### B.1.1 What Are Nanomaterials?

Nanomaterials are materials that range in scale from 1 to 1,000 nm. Due to their small size, these materials possess unique properties that are not seen in the "bulk" or "volume" effects. In bulk materials the *composition*, i.e., types of atoms, bonding between them, and ratios involved, influence the properties of a material. However, in the nanoscale, the properties change, and while the type of atoms present and their relative orientations are still important, "surface area effects", or quantum effects, become much more important and dictate the material properties. These effects are due to the *size*, i.e., diameter, thickness, and geometry, of the material, which, at these low dimensions, can have a drastic effect on quantized states and thus the properties of a material.

### B.1.2 Types of Nanomaterials

Many nanomaterials can be found in both natural and synthetic forms as shown in Fig B-1. Nanomaterials can be either organic (carbon containing) or inorganic (noncarbon containing). Organic nanomaterials include lotus leaves, bird feathers, graphene, and carbon nanotubes, while inorganic materials include opals, dyes, and quantum dots.

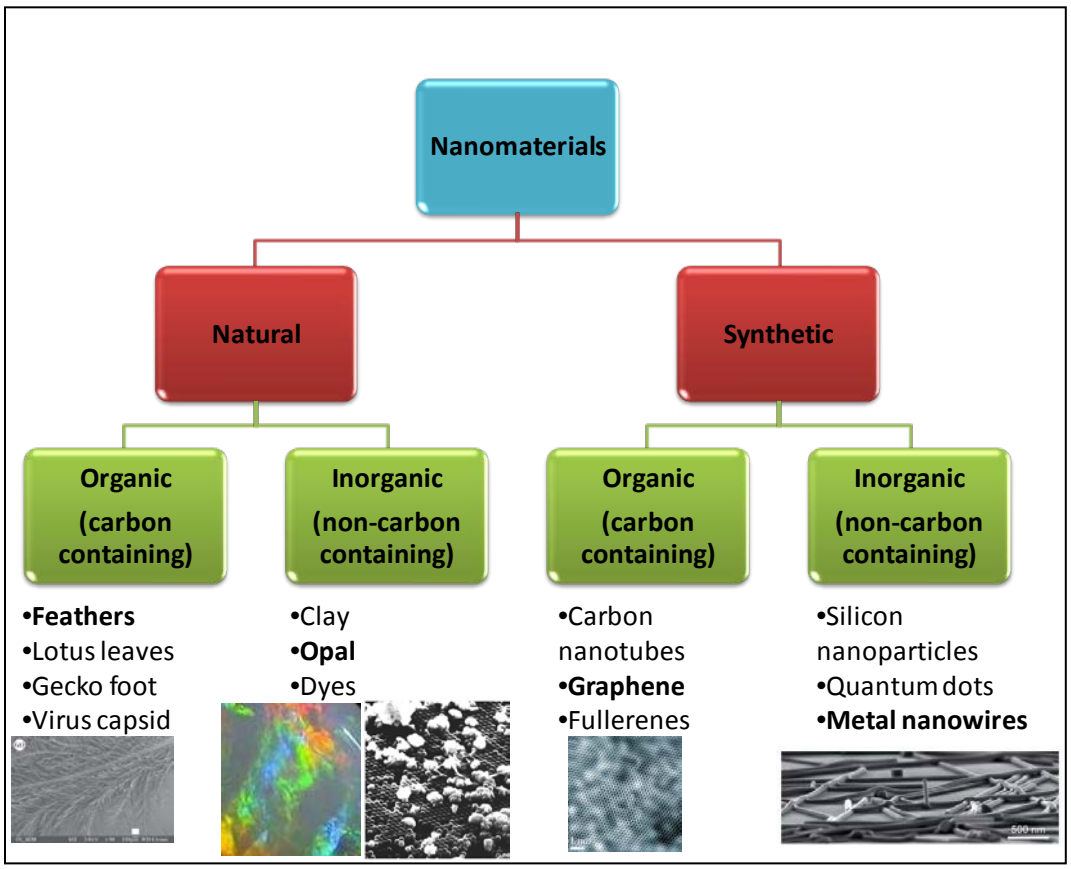


Fig. B-1 Classification scheme for nanomaterials

## B.2 Superhydrophobic Coatings

Making materials that are hydrophobic or superhydrophobic at the nanoscale can be approached in 2 ways. The first is through chemical modification where certain nonpolar molecules such as fatty acids or oils coat a surface and repel polar molecules such as water. This is why water cannot be mixed with oil. The second approach is commonly used in nature and involves covering the surface with nanostructures. For example, the surface of the lotus leaf is coated with cone-shaped nanostructures that reduce the surface area that the water comes into contact with. This reduced area makes it harder for the water molecules to bind, thus making the surface hydrophobic.

## B.3 Experiment: Effect of Substrate on Superhydrophobic Coatings

Ultra Ever Dry (UED) is a 2-part coating that can be applied to virtually any substrate (base material) to make it superhydrophobic (Fig. B-2). UED coatings utilize a nanostructure that mimics the surface of the lotus leaf by using patterns of geometric shapes that create “peaks” or “high points” to reduce surface area. This reduced surface area causes the water droplets to bead up to high contact angles. You will test the effectiveness of this coating on several different substrates.

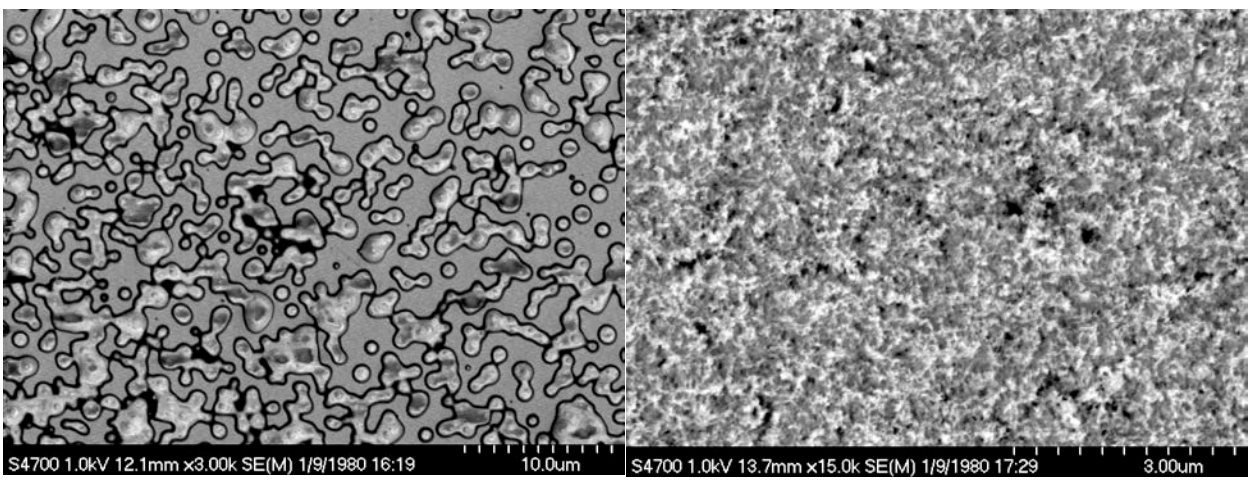


Fig. B-2 Scanning electron microscope (SEM) image of UED bottom coat (left) and top coat (right)

### B.3.1 Hypothesis

Will the substrate have an effect on the durability and effectiveness of UED coating? If so, why?

Predict the qualities that an ideal substrate would possess.

### B.3.2 Applying UED

*Completed by US Army Research Laboratory staff beforehand.*

1. Sand substrate with fine grit sandpaper for increased surface adhesion.
2. Clean and dry substrate.
3. Mix bottom coat for 5 min.
4. Apply uniform coating with sprayer and allow to dry for 30 min.
5. Mix top coat for 5 min.
6. Apply uniform coating with sprayer and allow to dry for 2 h.

### B.3.3 Testing Substrate Effect on UED Coating

To test the effect of substrate on the effectiveness of the UED, you will take the coated substrates to various testing stations and record the ability of the coated substrates to repel the test liquids.

# Appendix C. Data Collection

This appendix appears in its original form, without editorial change.

# Data Collection

| | Wood | Metal | Polycarbonate | Brick | Cloth | Cotton Ball | Glove | Paper | Total: |
|---|---|---|---|---|---|---|---|---|---|
| **Honey** | | | | | | | | | |
| **Water** | | | | | | | | | |
| **Mud** | | | | | | | | | |
| **Paint** | | | | | | | | | |
| **Syrup** | | | | | | | | | |
| **Oil** | | | | | | | | | |
| **Concrete** | | | | | | | | | |
| **Total:** | | | | | | | | | |

1) All of the fluid stuck
2) Most of the fluid stuck
3) Some of the fluid stuck
4) Almost no fluid stuck
5) Fluid did not stick

Fill in the table above by determining how well each material repels each fluid. Rank the materials from 1 to 5 using the legend. After testing each combination of material and fluid, add up the totals and compare.

# Appendix D. Postlab Questions

This appendix appears in its original form, without editorial change.

# Post Lab

**Question 1:** Which material (wood, fabric etc.) served as the best substrate?

Why?

**Question 2:** Which test liquids were the most repelled?

The least?

Is there a similarity among the liquids that were repelled?

**Question 3:** If the coatings did not exhibit omniphobic properties, state your hypothesis on why.

**Question 4:** How could the coatings be improved?

| | |
|---|---|
| 1 (PDF) | DEFENSE TECHNICAL<br>INFORMATION CTR<br>DTIC OCA |
| 2 (PDF) | DIRECTOR<br>US ARMY RESEARCH LAB<br>RDRL CIO LL<br>IMAL HRA MAIL & RECORDS MGMT |
| 1 (PDF) | GOVT PRINTG OFC<br>A MALHOTRA |
| 4 (PDF) | DIR USARL<br>RDRL WM<br>S KARNA<br>RDRL WMM A<br>M GRIEP<br>J SANDS<br>A WEST |

INTENTIONALLY LEFT BLANK.