Antibacterial Surface Coatings Applied for Food Safety

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Antibacterial Technology & Food Safety
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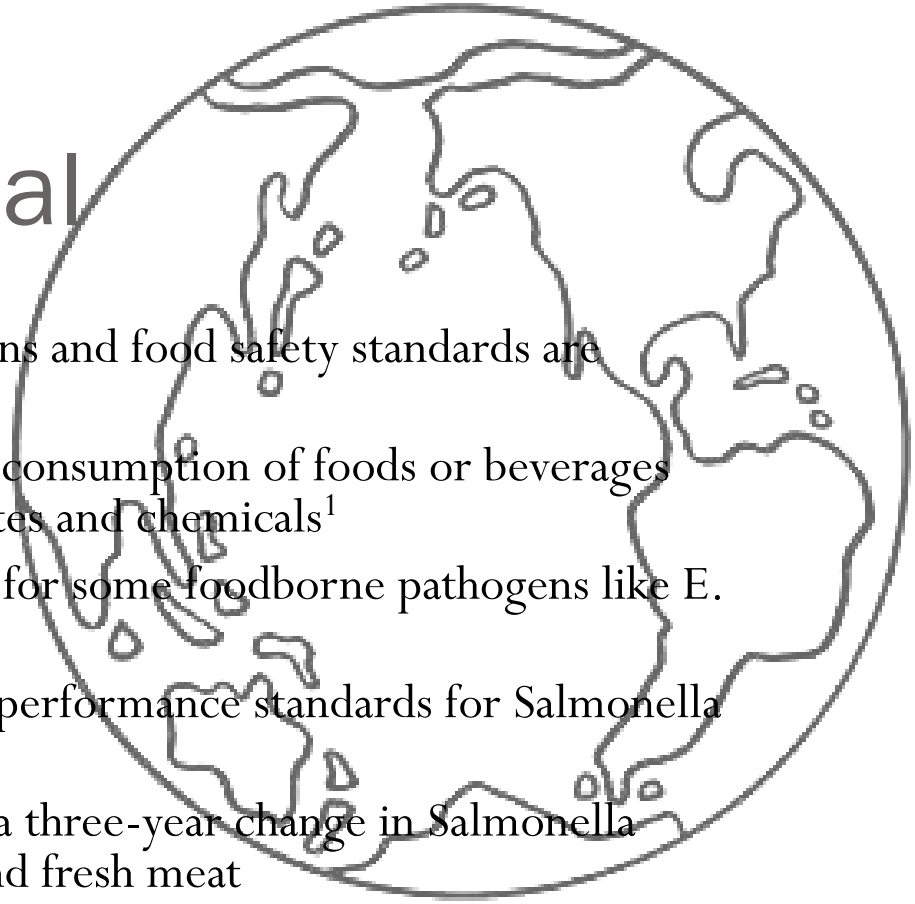
11th of October from 15:00 p.m. to 18:00 p.m., Congress Centrum North, Rheinsaal 5+6 of ANUGA (Cologne, Germany) 2011

Food safety is global



- Global monitoring of foodborne pathogens and food safety standards are becoming more stringent
- Foodborne illness or disease is caused by consumption of foods or beverages contaminated by bacteria, viruses, parasites and chemicals[1]
- "Adulterant" status means zero tolerance for some foodborne pathogens like E. coli O157:H7
- In the United States, new and increased performance standards for Salmonella and Campylobacter have been published
- The European Union is in the middle of a three-year change in Salmonella regulations for breeders, broiler farms and fresh meat
- The U.S. is increasing monitoring of non-O157 Shiga toxin-producing E. coli (STEC), and new and more sensitive tests will likely increase pressure to declare these pathogens as adulterants

Foodborne Illness

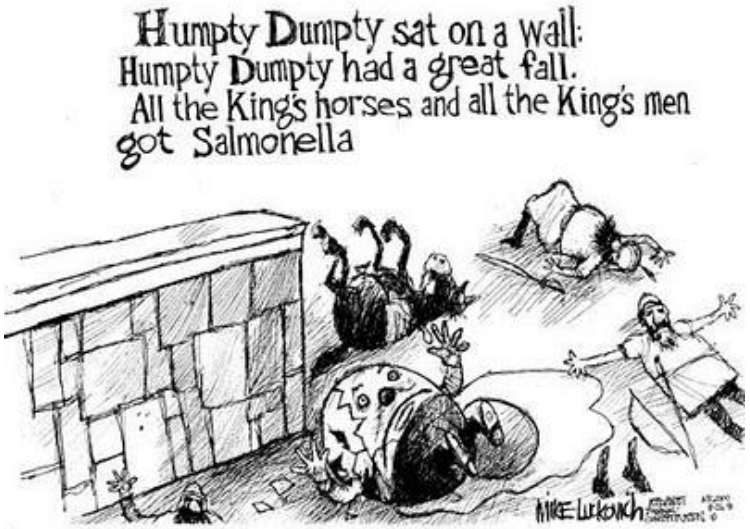
- In the United States alone, the Centers for Disease Control and Prevention (CDC) estimates[2]:
- Approximately 48 million Americans suffer from foodborne illnesses each year
- 128,000 people are hospitalized with foodborne illnesses annually
- 3,000 deaths are attributed each year to foodborne illness
- Salmonella is the leading cause of foodborne illness, and approximately 90 percent of U.S. illnesses, hospitalizations and deaths are due to seven pathogens: Salmonella, norovirus, Campylobacter,Toxoplasma, E. coli O157:H7, Listeria and Clostridium
- Globally, Argentina has the highest incidence of hemolytic uremic syndrome (caused by E. coli infections) with 12.2 cases/100,000 children younger than 5 years old and a 5 percent mortality rate among children with the syndrome[3]

Spinach

- **September 2006—**The FDA announced that Dole brand spinach was contaminated with E. coli O157:H7. Tests performed on samples of a bag of Dole spinach consumed by a New Mexico woman inflicted with E. coli confirmed the Dole spinach as the source of the outbreak.
- The FDA has attributed 204 cases of E. coli O157:H7 to contaminated spinach. At least 102 hospitalizations resulted from this outbreak and at least one death is blamed on the tainted spinach.
- In September 2006, the Food and Drug Administration expanded its warning against eating bagged spinach to include all fresh spinach.
- The victims are infected with the strain of E. coli called 0157:H7. Several of those infected during this outbreak have been diagnosed with hemolytic uremic syndrome, a serious form of kidney failure.

Eggs

- 2010, the current recall of eggs in their shells, or "shell eggs," is part of an ongoing and intensive investigation by local, state, and federal officials into the cause of recent cases of *Salmonella* Enteritidis.
- This recall affects shell eggs produced by Wright County Egg of Galt, Iowa. The eggs are packaged under different brand names and distributed nationwide.
- The shell eggs may contain *Salmonella* Enteritidis (SE) and may cause serious illness.
- *Salmonella* can cause serious and sometimes fatal infections in young children, frail or elderly people, and others with weakened immune systems.



Peanuts

- In 2009, the Peanut Corporation of America issued a world-wide recall for products it had made over the past six months, after eight people had died and more than 19,000 had fallen ill with salmonella poisoning as a result of contamination.
- The company's factory in Blakely, Ga., which was the source of the contamination, supplied some of the largest food makers in the nation.

A ConAgra plant changed its safety procedures after salmonella in Peter Pan peanut butter sickened people in 2007.

Cucumbers and soybeans

L&M Companies, Inc. of Raleigh, NC is issuing a voluntary recall of one lot (1590 cartons) of whole cucumbers because it has the potential to be contaminated with Salmonella. April 2011

- Fatality balance of the epidemic linked to the killer bacterium that hit Europe in 2011 is now 22 dead (21 Germany, 1 Sweden).
- Investigators discovered traces of the bacteria in a farming and organic gardening, operating bean sprouts in the locality of Bienenbüttel, 75 km south of Hamburg.
- German scientists now suggest other avenues, such as biogas production centers, where organic waste have released new bacteria.
- The epidemic has reached nearly 2000 people in Europe, and first strikes northern Germany. Hospitals in Hamburg postponed non-urgent operations to accommodate victims of E. coli.

Ground Beef

- **September 2011**—Tyson Fresh Meats Inc. announced the recall of 131,300 pounds of ground beef that could be contaminated with E. Coli. The U.S. Department of Agriculture announced that a sample of ground beef tested positive for E. coli.
- **September 2011**—Manning Beef has recalled 80,000 pounds of beef products th may be contaminated with E. coli. The USDA's Food and Safety Inspection Servic said the recall was due, in part, to insanitary conditions that resulted in an unusually high number of confirmed positive E. coli test results.

Colorado, USA Cantaloupes

Possibly infected with listeria, cantaloupes rot in the heat at Jensen Farms near Holly, Colo.
Photo: Ed Andrieski / AP

- September 2011 - Jensen Farms, of Holly, CO is voluntarily recalling their shipments of Rocky Ford whole cantaloupe because they have the potential to be contaminated with Listeria.
- The whole cantaloupes in question were shipped between July 29th, 2011 and September 10th 2011, and distributed to the following states: IL, WY, TN, UT, TX, CO, MN, KS, NM, NC, MO, NE, OK, AZ, NJ, NY, PA.
- The recall involves a food scare that has sickened people from Wyoming to Maryland with a death toll at 17.
- The Center for Disease Control and Prevention rated the outbreak of listeria among cantaloupe from Colorado's Jensen Farms the deadliest in a decade.
- The CDC put the death toll from listeria at 13, while 72 people have been infected.

What do consumers say?

- According to a 2009 American Society for Quality (ASQ) study of U.S. consumers[4]:
  - 93 percent said food manufacturers, growers or suppliers should be held legally responsible when individuals are fatally sickened by tainted food
  - 93 percent were aware of food recalls due to health and safety concerns in the last three years — up from 79 percent in a similar study conducted in 2007
  - 92 percent are "somewhat concerned" or "very concerned" about food recalls
  - During a food recall, 47 percent would purchase another brand until the recalled brand is safe — but 27 percent said they would not purchase any brand made by the manufacturer of the recalled product

Do consumers remember?

A 2008 study by Gallup revealed that 60 percent of U.S. consumers say they avoid certain foods or brands as a result of government-issued food-safety advisories or recalls.[5]

YES!

Impact on Food Industry

Meat plant sanitation in US
Photo courtesy of Dr. Ty Lawrence, Professor of Meat Science

- Meat and poultry packers and processors have invested significant time and money on food-safety interventions in the last few years but continue to face safety-related recalls
- Recalls erode consumer confidence in the safety of the food supply — especially high-profile recalls involving major manufacturers and/or massive amounts of food.
- Recalls result in lost revenue, cause long-term damage to processor and retailer brands, and can result in increased litigation and liability for processors.

Industry Needs

Food producers and processors are in desperate need of new, innovative interventions that will help them reduce foodborne pathogens and the risk of potential human illness, product recalls and damage to their brands while remaining compliant with new government regulations.[7]

Industry Responsibility

- All of this data reinforces the need for multiple pre-and post-harvest food-safety interventions to help meet the growing demand for a safe and abundant food supply
- The industry must accept this challenge with new research and technology.
- A promising way to increase health and safety in the food industry is the development of new materials that can be easily implemented into existing equipment.
- **Researchers worldwide are responding to this need with the creation of novel materials.**

Materials for the Future

New R&D

- Despite considerable research and development efforts, the problem of contaminations related to food preparation and packaging persists.
- Traditional cleaning methods, such as aerosolized disinfectant sprays or wipes have a limited effectiveness.
- There is a strong need to mitigate bacterial colonization by engendering materials with properties that include surface chemistry and surface roughness which are unfavorable for bacterial attachment and growth.
- The food industry is in desperate need of new, innovative interventions that will help reduce foodborne pathogens and product recalls while remaining compliant with new government regulations.

Silestone

- Silestone is a solid surface material frequently used in kitchen and baths as a countertop surface. Made primarily of quartz, Silestone also consists of a small amount of plastic.
- Silestone is scratch-resistant and scorch-resistant since it is made of quartz, which is one of the hardest minerals found in nature, according to the Silestone website.
- One of the most advantageous features of Silestone is that it has built-in antimicrobial protection to prevent bacteria growth.

  This is accomplished through the Incorporation of nanoparticles of Silver into the quartz mixture.
- What is a nanoparticle?

  How can it contribute to future material development?

A quartz countertop

What does nano mean?

- Nano is vvvveeeerrrrryyyy small.
- 1 Nano = 1 billionth
- Metric system

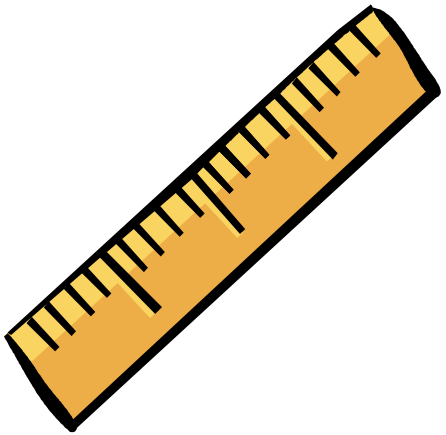
  1 km = 1000 m

  1 m = 100 cm

  1 m = 1000 mm

  1 m = 1,000,000 μm (1 million)

  1 m = 1,000,000,000 nm (1 billion)



The effect of size

vs

The effect of size

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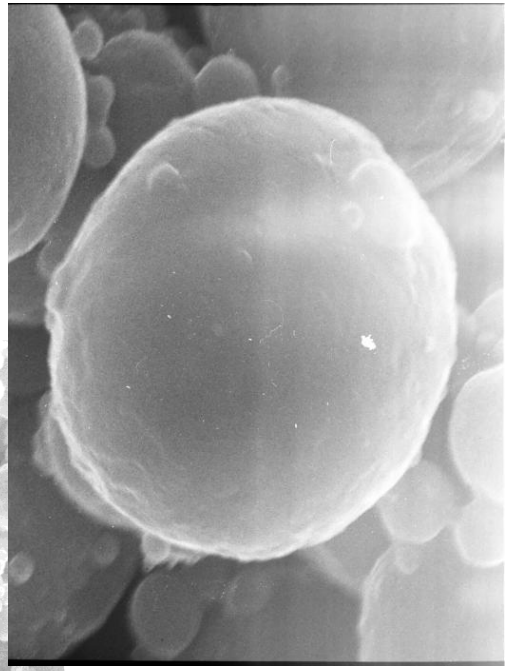
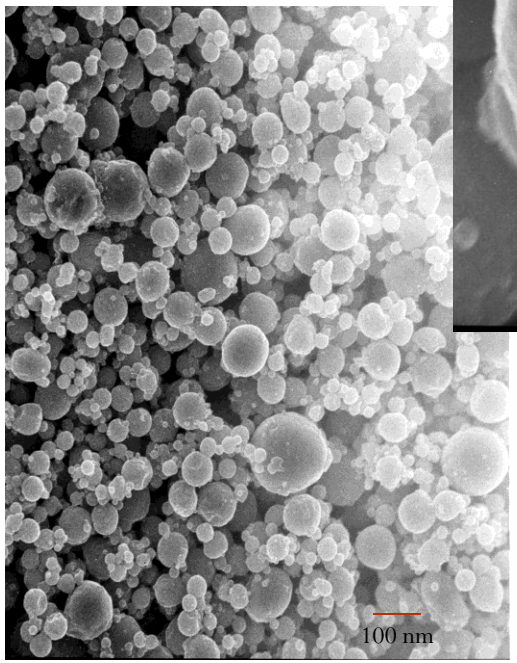
The effect of size

Nano-Scale Aluminum

- Significantly higher surface area-to-volume ratio → more contact between fuel and oxidizer is achieved.
- Unique thermal properties →higher absorbance coefficient, reduced ignition temperature and time.
- Allow increased homogeneity within the reactant mixture →improved uniformity of product microstructure.

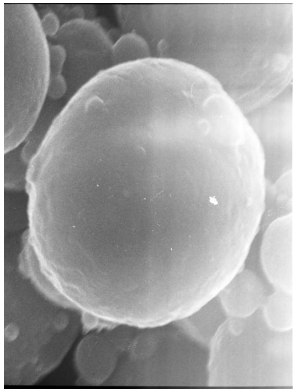
SEM of 4 um Al





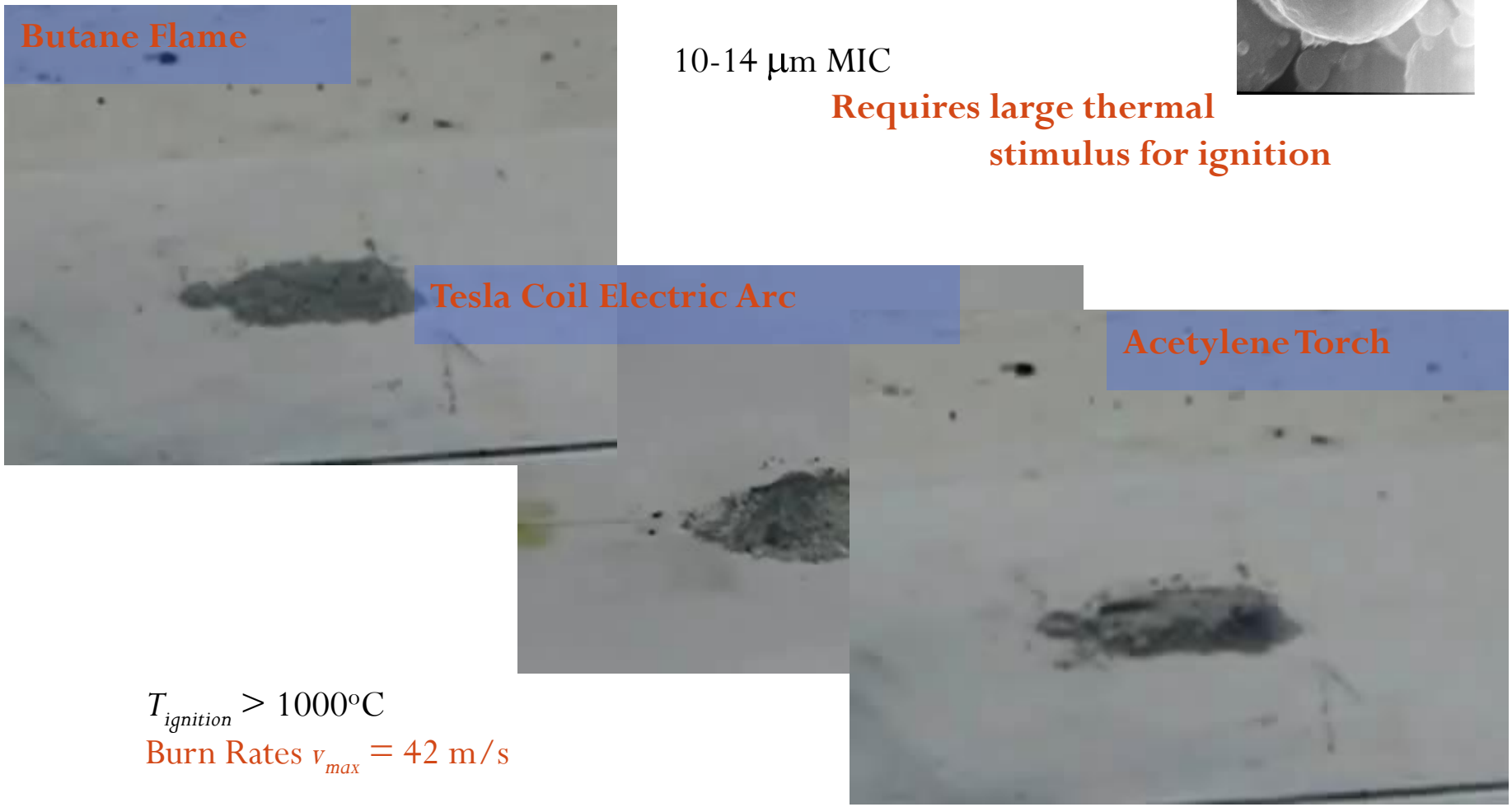
SEM of 100 nm Al

Insensitive Traditional Micron-Aluminum Thermites



10-14 μm MIC

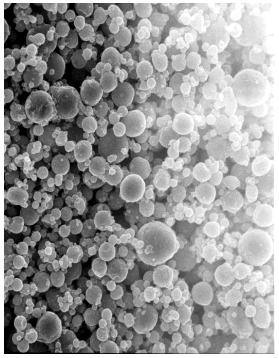
Requires large thermal stimulus for ignition



$T_{ignition} > 1000^{o}C$

Burn Rates $v_{max} = 42$ m/s

Super-Sensitive Nano-Aluminum Thermites



Minimal ignition energy requirement

$T_{ignition} < 500^{o}C$

Faster Burn Rates

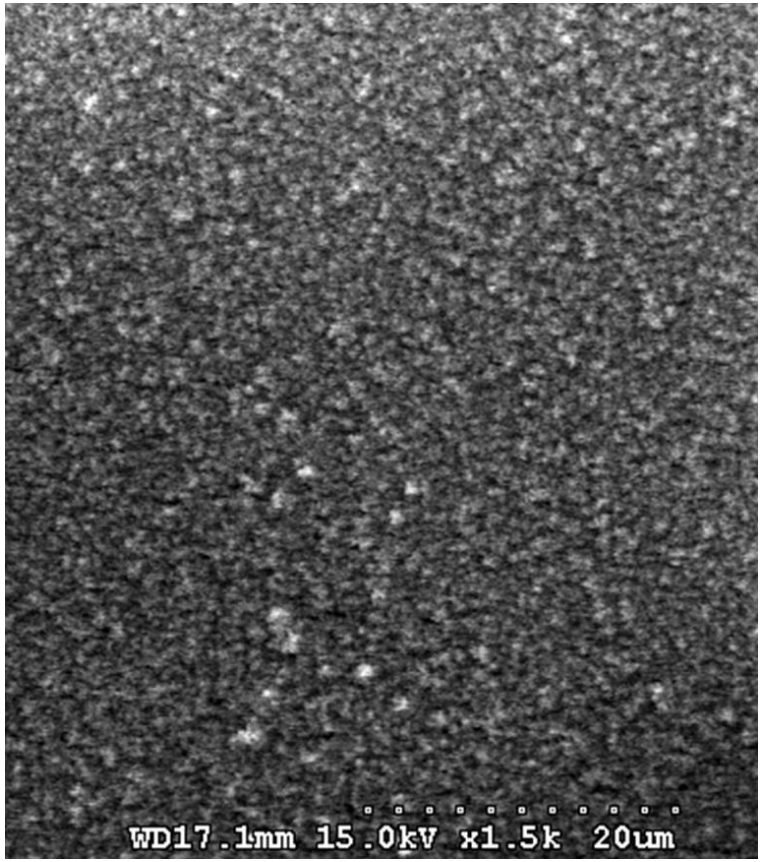
$v_{max} > 470 m/s$

Aluminum melting temperature

$T_{mp} = 660^{o}C$

New metal alloys

- Energetic material composites are often used to synthesize materials that have industrial applications as abrasives, cutting tools, heating elements, and nuclear safety shields.
- We recently discovered that by tailoring reactants, nanocomposites can produce metallic foams made of pores only nanometers wide.
- The extraordinarily high surface areas of these foams suggest that by choosing the reactant composition to include materials with antibacterial properties the product foam could be used to effectively destroy bacteria.



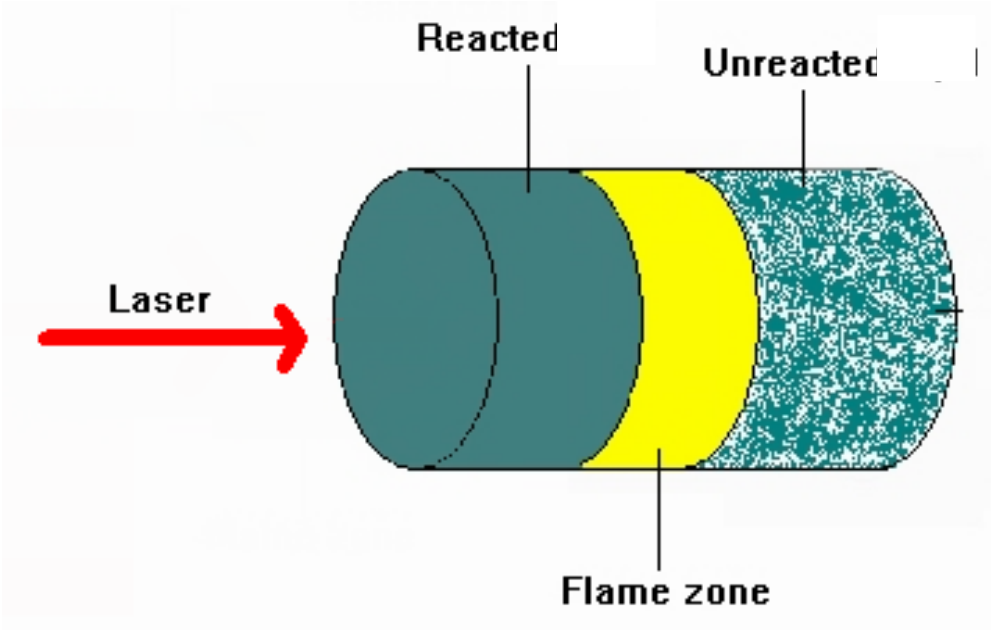
SEM micrograph of metallic nano-foam.

How do we make these new alloys?

Combustion Synthesis

There are two main types of combustion synthesis:

1. **volumetric or thermal explosion (TE) – occurs when the entire sample is heated to a uniform temperature and spontaneous reaction occurs.**
2. **self-propagating high-temperature (SHS) – one end of the sample is ignited and the reactants contain enough chemical energy for self-propagation.**

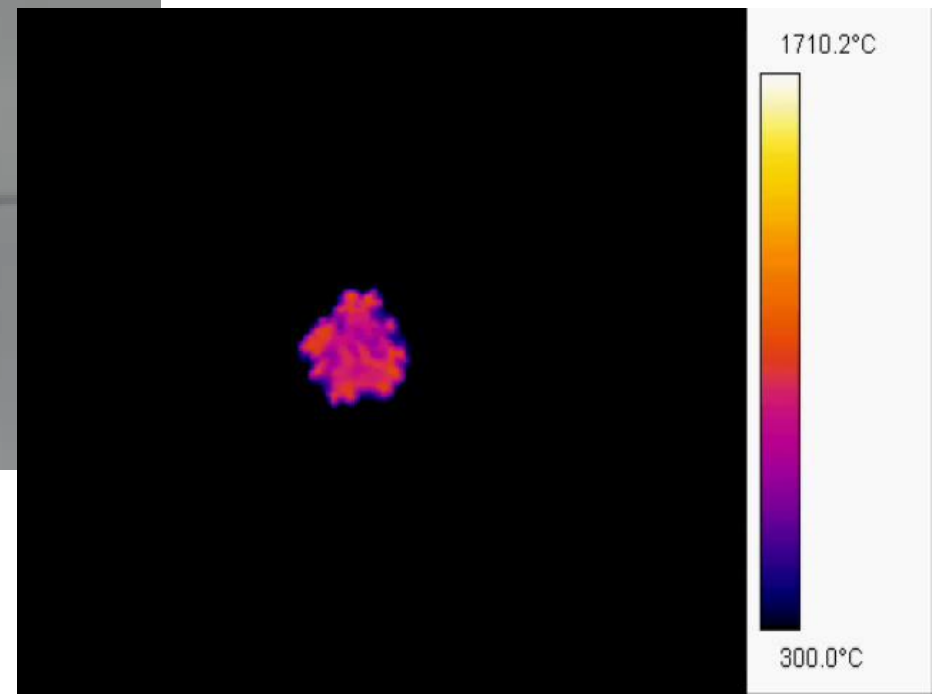


SHS of pressed reactants

Infrared Imaging of Combustion Synthesis (powders)

Video Camera

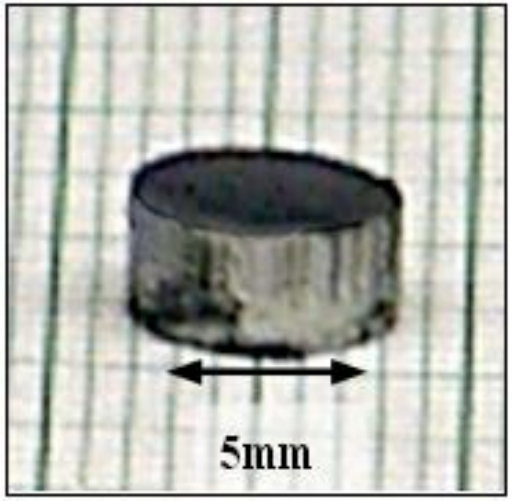
80 nm Al burning in air

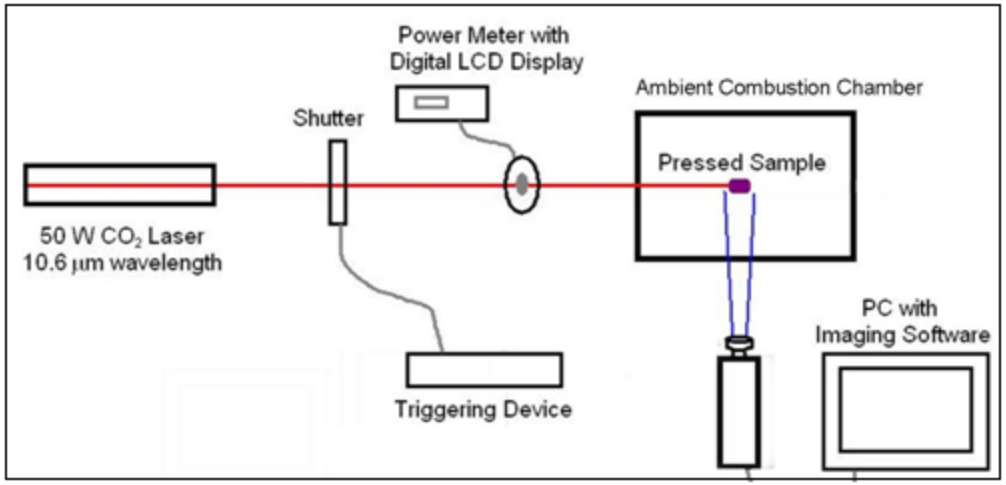


IR Video

Combustion Synthesis Set-up

- Creating highly porous antibacterial solid materials through combustion synthesis.
- Synthesizing reactants is a function of the mixture composition and thermo-physical chemistry coupled with the combustion process.
- Heating rate may play a critical role in the biocidal properties of the final product, so both modes of synthesis will be examined.

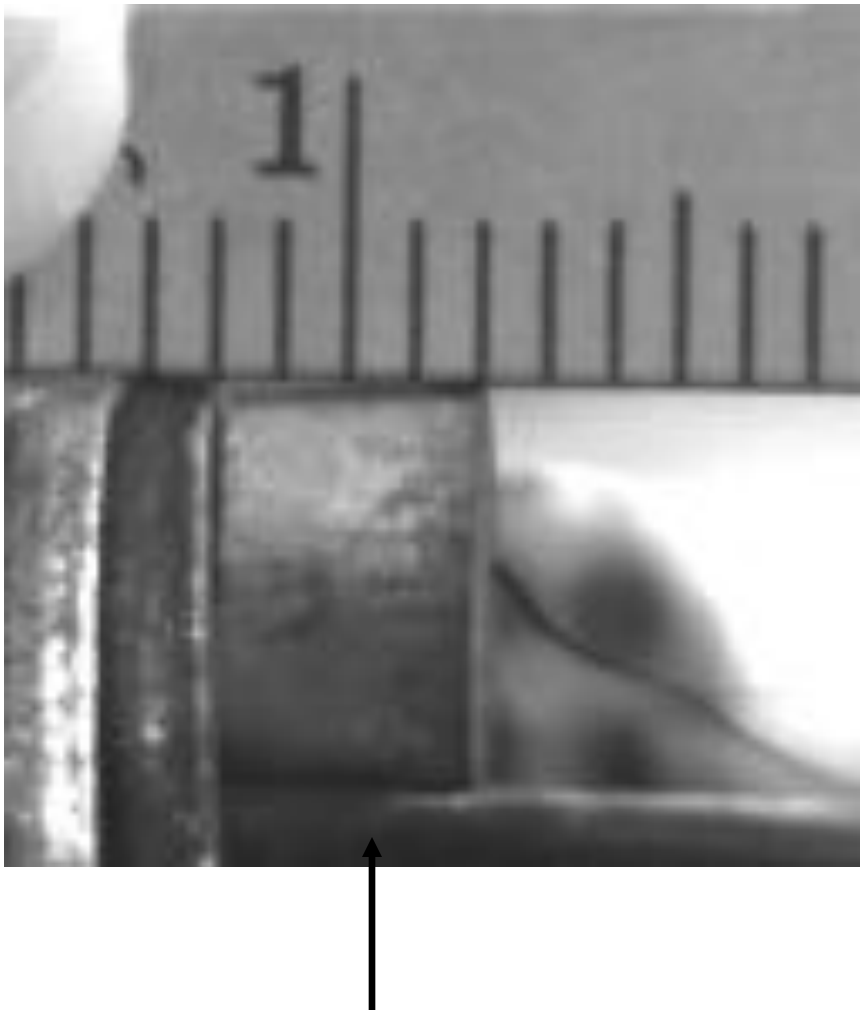




SHS Experimental set-up

Sample Preparation

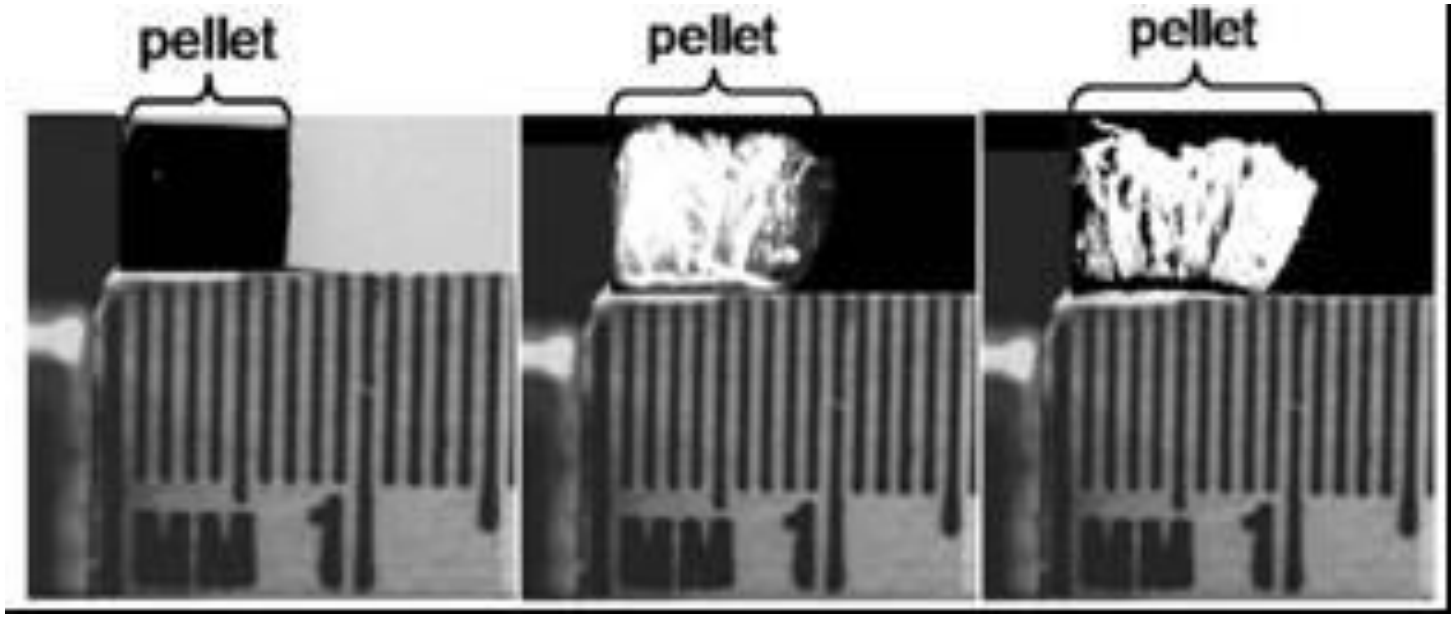
- 1:1 molar ratio of nanoparticles used for all sets of experiments.
- Particles were immersed in a solution and mixed using ultrasonification.
- Solution was then allowed to evaporate.
- Powder mixture was cold pressed in a uni-axial die to create cylindrical pellets with a 6.5 mm diameter.



Pressed Pellet

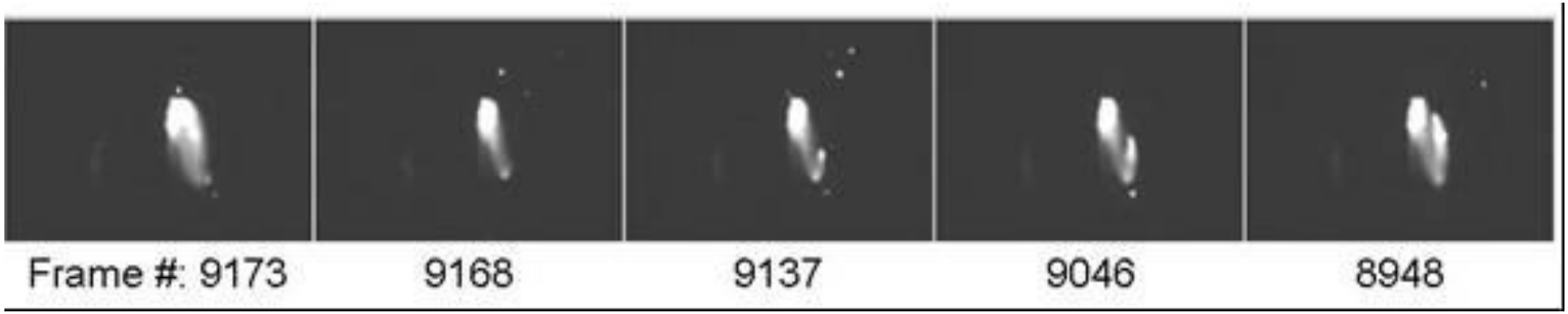
Metallic Coatings

- Examination of the SHS of a porous material using nano-particle reactants.
- Incorporation a gasifying agent as an intrinsic part of the nano-scale particle rather than an additive in the form of a powder or granular material.

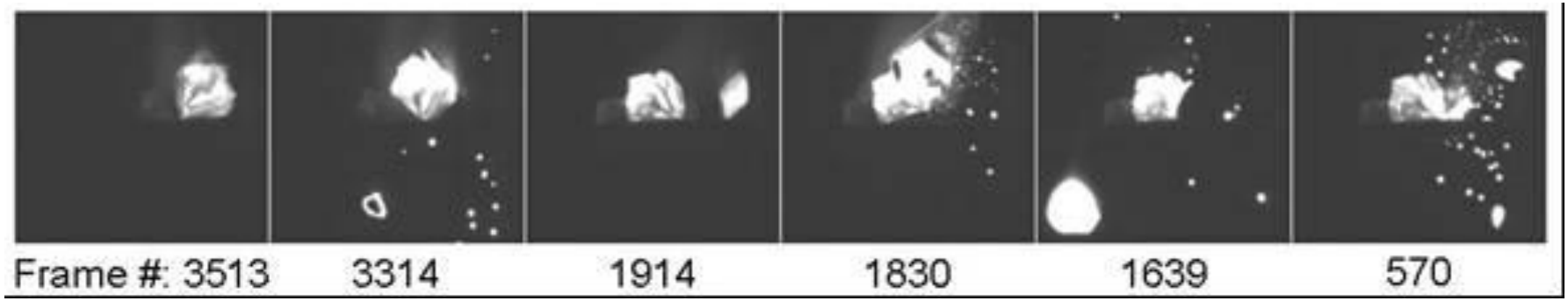


Density of Metallic Coatings

Still images of the reaction of a 60% TMD pellet exhibiting planar reaction wave

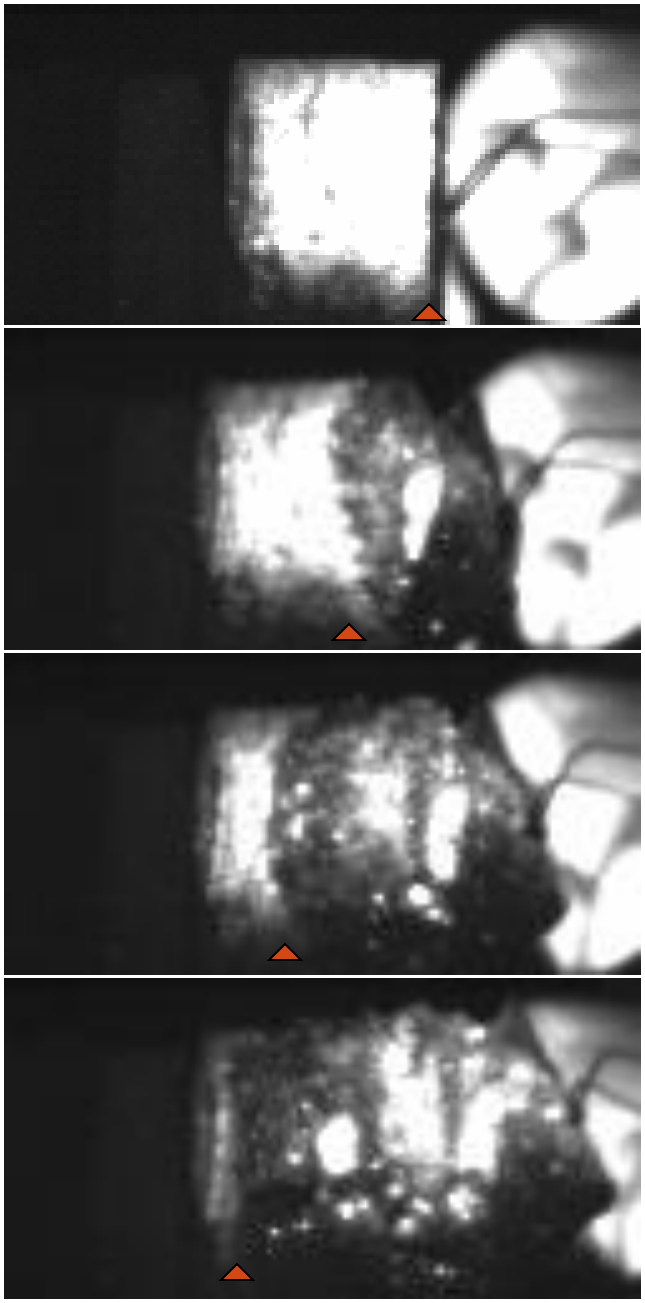


Still images of the reaction of a 30% TMD pellet exhibiting a scintillating reaction



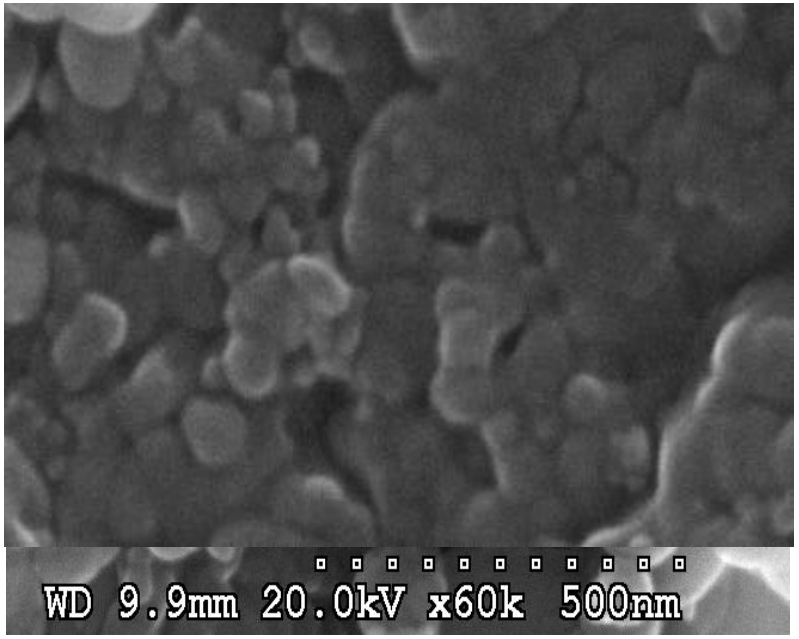
Coating

- These are images taken at 120 μs intervals by a high speed camera.
- The flame font moves through the reactant powders leaving a new, solid alloyed structure behind.
- This material can be used to coat existing metal components.
- Metal will be coated with powder and then an ignition source is applied leaving behind metallic surface coating.



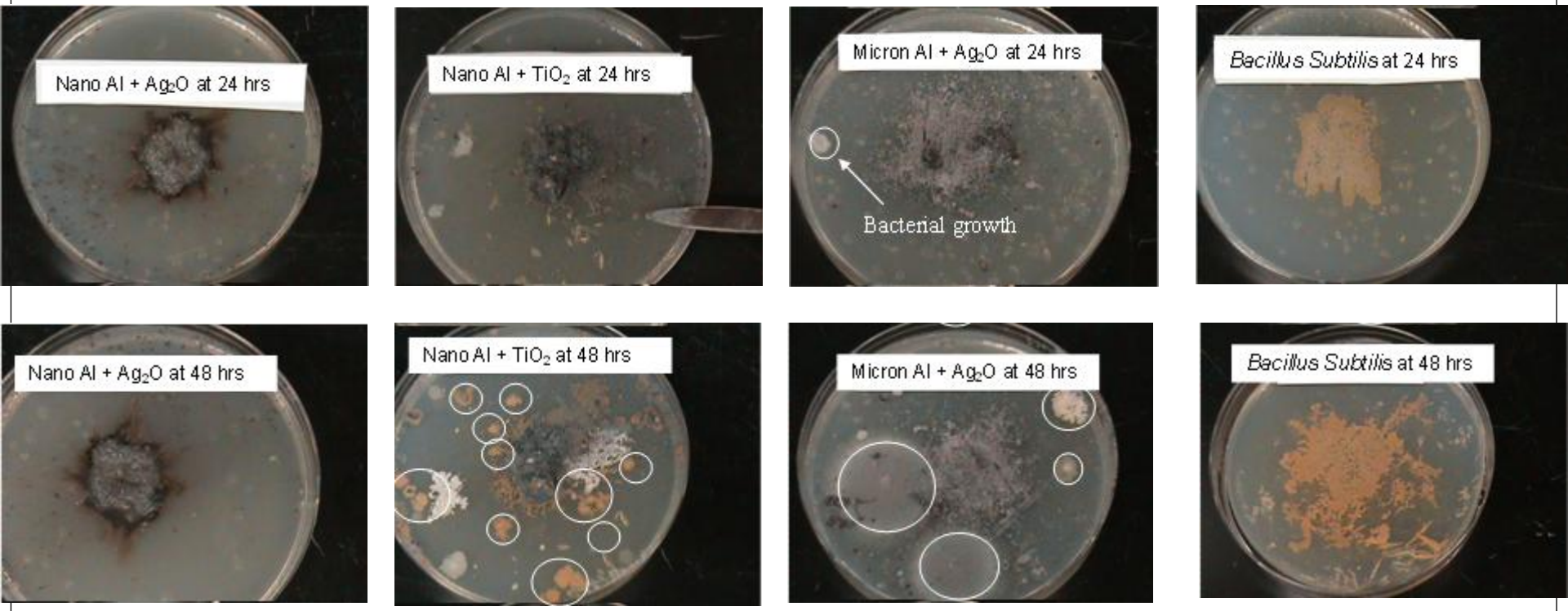
Microstructure of Metallic Coatings

- Experiments are performed to demonstrate the bacterial (Bacillus Subtillis) growth kinetics on synthesized foams.
- Mixtures composed of nano-scale and and micron-scale reactants.
- Each mixture was prepared for a stoichiometric equivalence ratio of 1.0 and mixed by sonication.
- Each sample contained 100 mg of reactant mixture in powder or cold pressed.



SEM micrograph of metallic coating

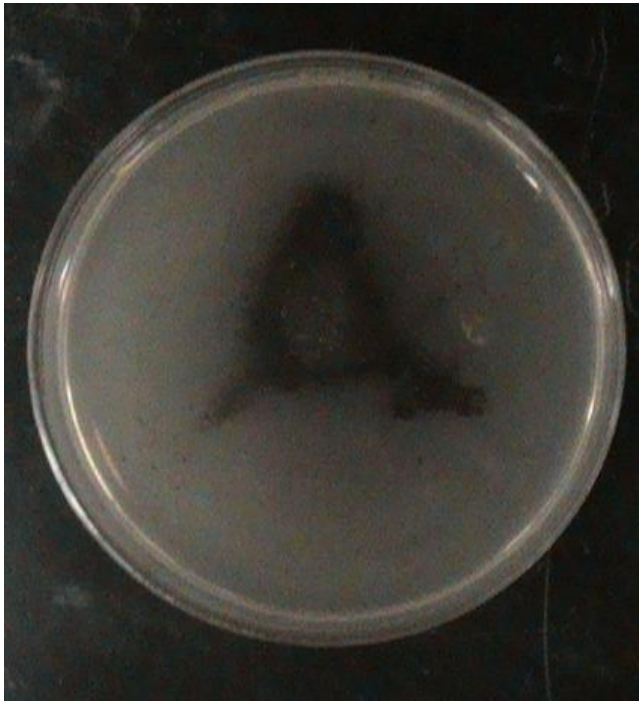
Antibacterial Behavior of Coatings



- After 48 hours, there is growth on all of the foams, except for the nanoparticle composition which shows no sign of any bacteria.

Different types of bacteria

BT 48 hours



E. coli 48 hours

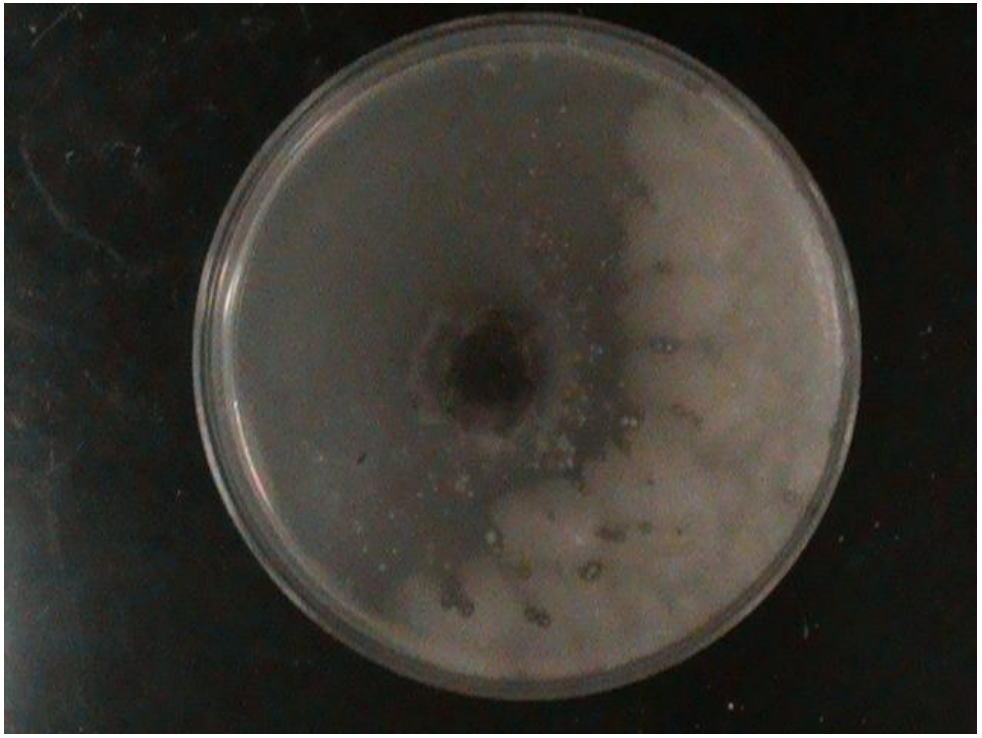
BA 48 hours

No Bacterial Growth!

Combustion Synthesis Results

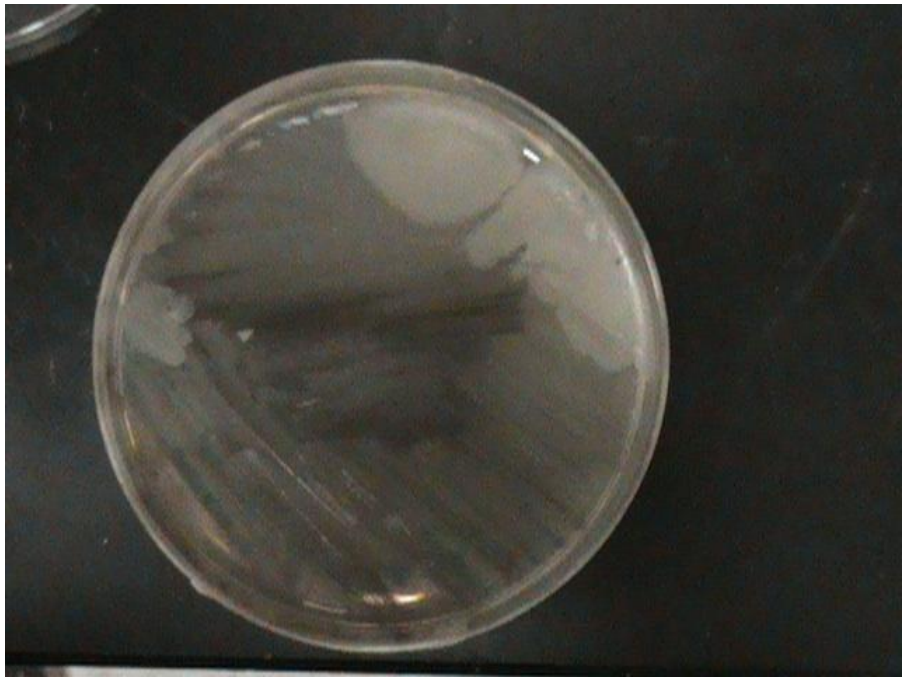
- E.coli applied to our new metal coating using several different bacterial application methods:
- Direct with swirling
- Swabbing
- Agar overlay

Still no growth on metal at 48 hours using any method!



Agar overlay—48 hours

Swabbing samples with E.coli



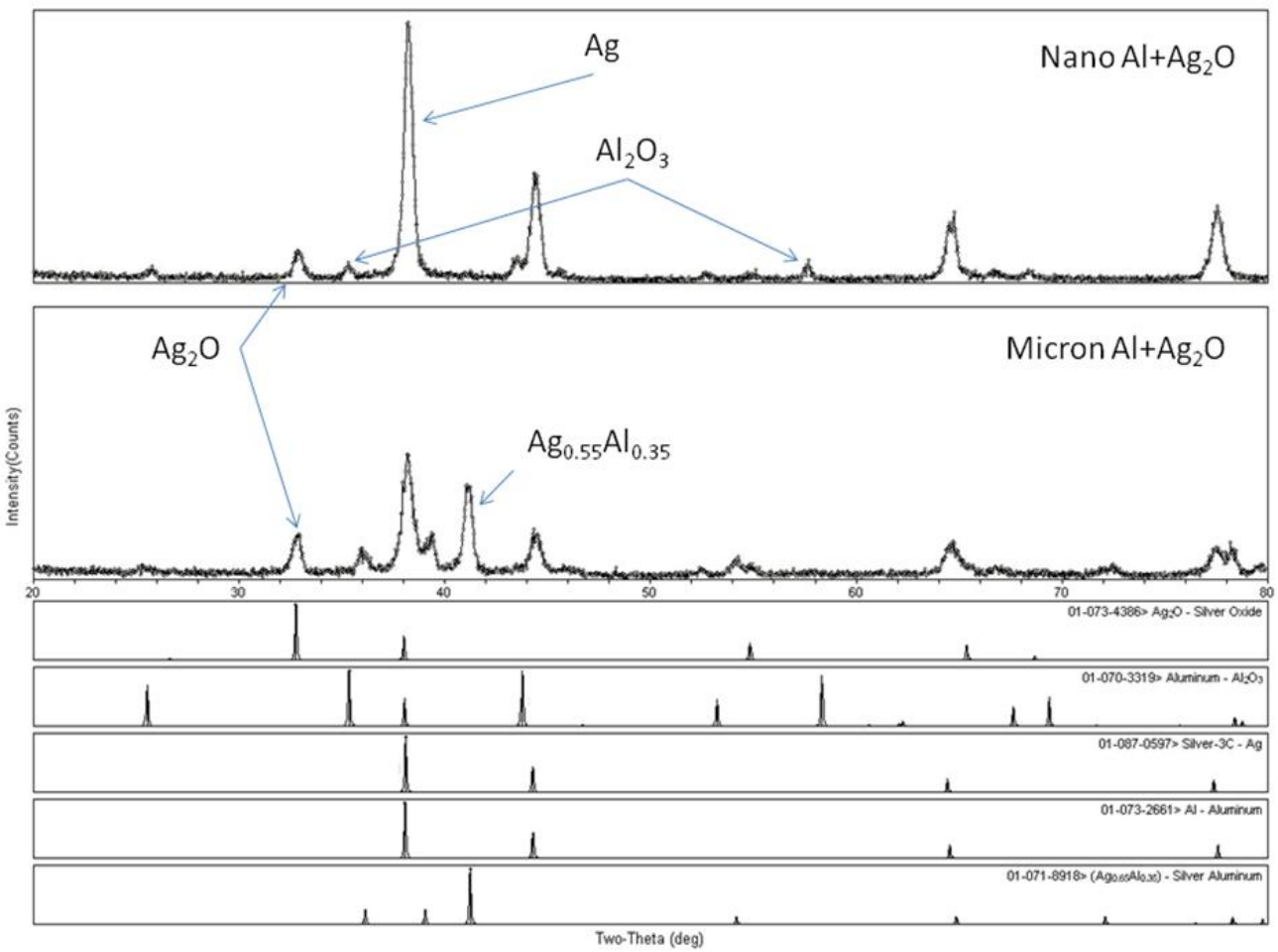
Swabbed a) New nano-structured metal with E.coli

b) Other metal surface with E.coli

No growth!

Growth all over!

XRD of Antibacterial Metallic Coating



- XRD data gives insight into the actual product composition of the metallic nanofoams.
- The nano Al/Ag_2O show significant percentages of Ag in the products while the micron Al/Ag_2O samples show high amounts of $Ag_{0.55}Al_{0.35}$.

Future of Antibacterial Materials

- Retailer initiatives are influencing the demand for validated, efficacious interventions and testing.
- In the producer segment, industry-driven quality assurance programs are impacting demand for new food-safety interventions.
- There is more complexity as to how the live-animal side impacts food-safety issues and the interactions that can occur through the entire supply chain.

Conclusions

- Bacterial contamination in food industries that lead to the risk of potential human illness create a major public health issue.
- There is a strong need to mitigate bacterial colonization by engendering materials with properties that include surface chemistry and surface roughness which are unfavorable for bacterial attachment and growth.
- The food industry is in desperate need of new, innovative interventions that will help reduce foodborne pathogens and product recalls while remaining compliant with new government regulations.
- Researchers worldwide are responding to this need with the creation of novel materials.
- One such material is a nano-structured metallic alloy created by combustion synthesis. This material is created by a reaction that can produce a self-propagating heat wave that will synthesize metallic alloys made of pores only nanometers wide that inherently exhibits antibacterial properties.
- The extraordinarily high surface areas these materials possess serve as an excellent platform for the neutralization of bacteria. These newly synthesized alloys present a novel approach to bacterial neutralization.

Questions?

"While the challenges are significant, progress is being made. Food safety is a non-competitive issue and, as a result, accelerated advancement is evident. Companies that may be competitors in the protein sector are partners in food safety. Much progress has been made relative to the discovery and sharing of new information. People involved in each link of the food chain — producers, transportation workers, processors, suppliers, employees, retailers and customers — are becoming more accountable for food-safety innovation."

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