

Creating the Needed Materials for the 21st Century

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Introduction

- As we know – “materials” is the stuff things are made of.
- There is not an endless supply of “stuff” and our requirements for that stuff is becoming more and more extreme. How can we create the things we need as we come up against these issues?
- Today I am going to give you some of my thoughts for materials as I see them moving forward.



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My first thought is about how much we haven't changed

- We make relatively simple materials and then assemble them together.
 - We find or make a material
 - We assess the properties we know how to assess
 - We create the materials at close-to-final size and then we often machine it to its final shape
 - We attach it to other materials to create a macrocomposite.



From humanorigins.si.edu (Smithsonian)



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I believe that our perspective is in the process of changing

- Our time today is, at least in part, a time to rethink how we do things.
- It is a time to look at the horizons that we see for materials and move forward from those materials development tools we used in the 20th century.



From humanorigins.si.edu (Smithsonian)



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My next thought is on innovation

We often talk about innovation and how important it is

Webster: (1) The introduction of something new; (2) a new idea, method or device.

←
prehistory

After looking at a number of discussions of quantized innovations or timelines for when innovations happened, it seems that creativity (as we perceive it) has increased something like this curve.

Certainly, as a species, we have been very creative and along with knowledge, we seem to have an iterative process.

It seems that no matter what else is in the mixture, both the need to solve a problem and the materials technology to create the solution to the problem must be available for the solution to any non-software related technical problem.

1800 -
2000

major innovations



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year (logarithmic)

Device innovations follow needed discovery in materials

- Over time, device innovations have followed the materials that have allowed them to happen.
 - A hand adze has followed the ability to “machine” rocks
 - The sword followed the ability to metal
 - Lenses followed the ability to create clear glass
 - Optical fibers followed the ability to make fiberglass
 - Small affordable computing followed integrated circuits and chips which followed p/n junctions which followed semiconducting silicon
 - The Boeing Dreamliner follows the reliability improvements in PMCs



Another thought - Our socio-political environment creates a sense of the materials needs for the future

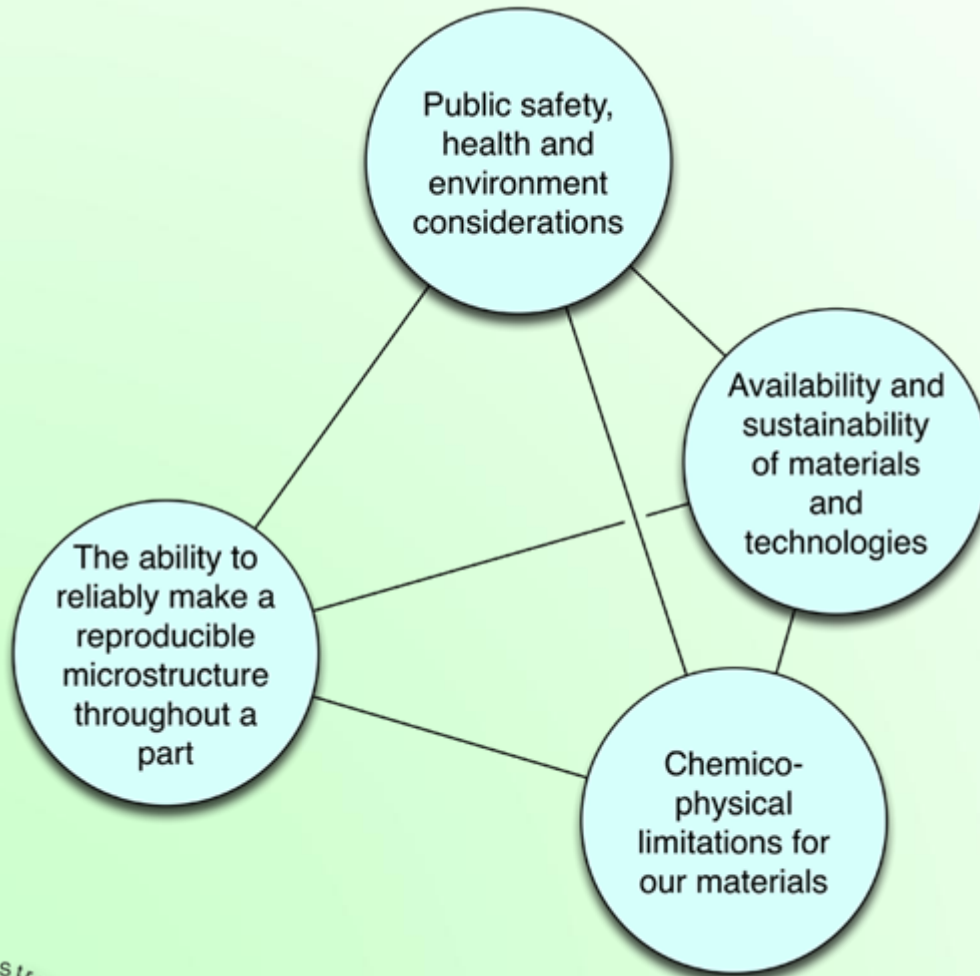
- Innovation is often the result of needs.
- In today's world, it is useful to see the drivers of technology within a national context:
- **Security**
 - Sensors, actuators and awareness
 - Information conduits, arrays and the like
 - Properties of need
- **Energy Effective Materials**
 - Lightweighting and multipurpose materials
 - Materials for extreme environments
 - More efficient transport electricity or decentralization of electricity production
 - Inventive thermal conducting and energy transforming materials
- **Materials Availability**
 - Sustainability
 - Thoughtful design of materials “systems” for appropriate properties within a service environment
- **Infrastructure**
 - Interconnectivity of services and rethinking interrelated service conduits



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Our limitations envelope will also drive our development



- What might our real limitations be.
- In truth we will always be constrained by the same set of limitations.
 - Physical factors
 - Technological factors
 - Availability factors
 - Environmental factors



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Public safety, environment and health



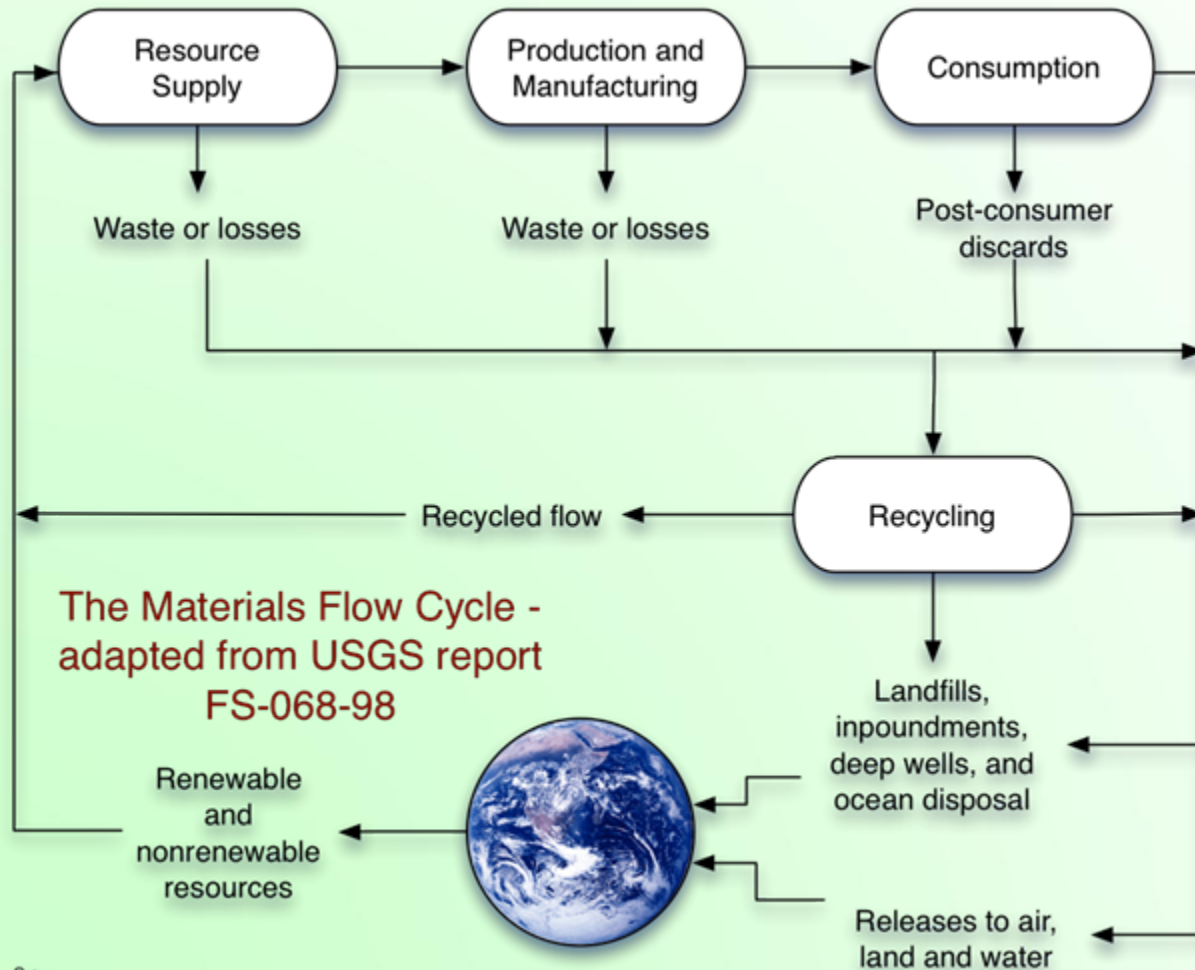
- It is communication, dialogue and transparency that will allow us to develop materials with the public's confidence.
 - We must take extra care to assure that the public has confidence that we are trying to create materials with EHS in mind.
 - Creating a transparent system will go a long way towards assuring people that we are trying to do things honestly.
 - Dialogue – communications through an honest discourse between the industry and the public sector should, in the long run, create a trust between the oft time adversaries allowing these more complex (and often frightening) materials to be valued and developed.
 - Along with dialogue, community participation will become necessary for companies to develop their needs hand in hand with communities.



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Sustainability and Availability of materials?



Although elements like Si will be with us for a good long time, there are some elements that will be difficult to both mine and reclaim that (Re for example) that will limit our ability to create using the materials that we have used and often that we – believe – that we need



Physical sciences

- As physical sciences, physics and chemistry give us a strong sense of our ultimate limitations.
 - Quantum level sizes below which our properties don't make sense
 - Chemical relations that govern how atoms relate
 - Limits on the properties that are related to the electronic structure of the atomically built environment.
 - Real time and size limitations for processing of materials

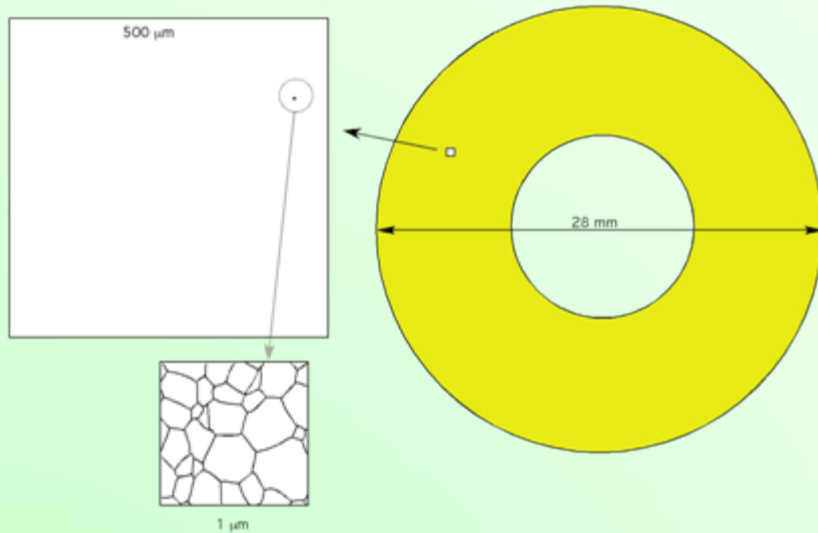


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Reliability is a preeminent watchword

- Our understanding of microstructure - property relationships is neither complete nor clear.
 - We have trouble controlling microstructures in real sized parts
 - We do not fully understand how microstructure affects all of our properties
- We will have to learn how to create, reliably recreate and assess our materials systems using QC tools.
- One possible control tool is to create a microstructural map (I have called validated microstructural assessment) en route to determining changes that can lead to issues we do not know are there.



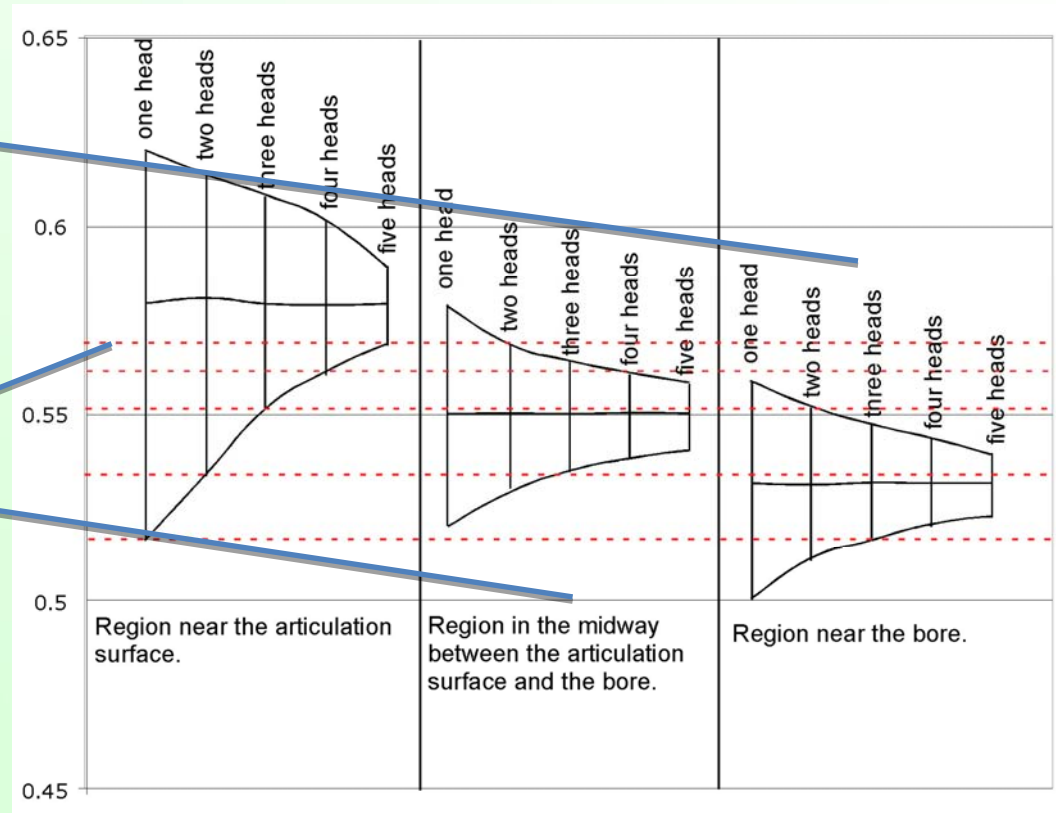
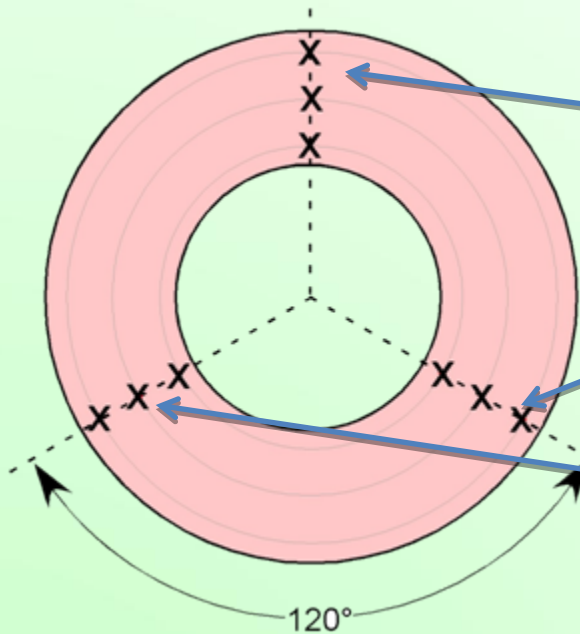
Assessment of a 28mm ceramic ball (with bore) used for a hip replacement



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Reliability - Validated Microstructural Assessment



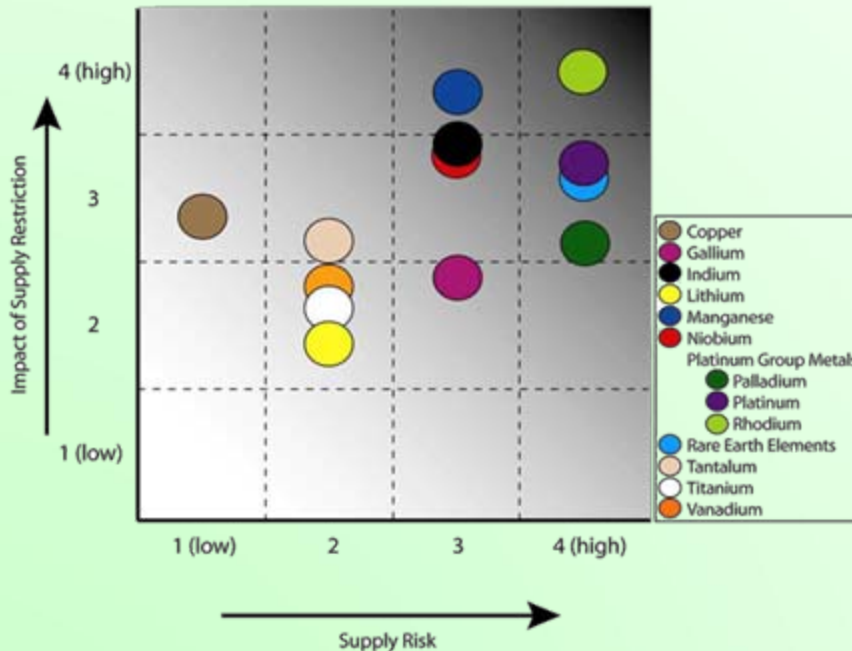
A real product of uniform grain size is not really as uniformly designed as we might like to think. (from Fischman JASTM Int 2004).



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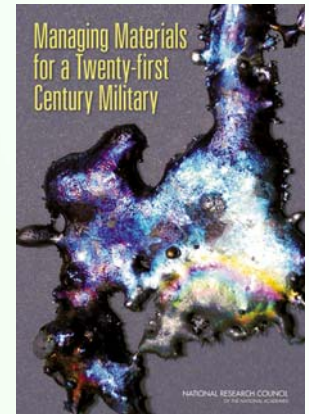
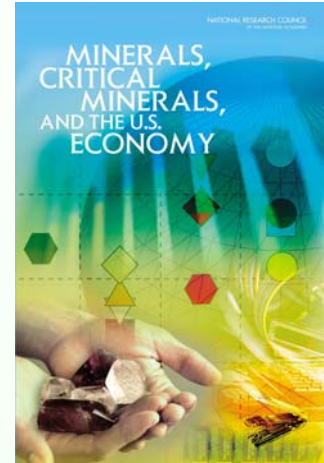
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Materials Availability



From, Minerals, Critical Minerals and the US Economy, National Research Council, 2008.

The relationship between a minerals availability and its significance in various supply chains was reviewed by a committee formed by the National Academies (one of their figures is to the left) that was done side by side by another committee that looked at the Defense National Stockpile Center and possible ways of improving the Department of Defense's management of materials for their critical need.



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The need to recreate infrastructure has potential to create materials needs quickly



- Materials will be on the forefront to improve security and energy efficiency from here on out as we rebuild and improve our national and international infrastructures.
- DHS has seen this and is rolling out their Advanced and High Performance Materials Database (advmat.org) NOW.
- To do things well, I believe that we will have to create a strategy that coordinates ALL of infrastructure.



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Next thought – we are now rethinking how we make materials

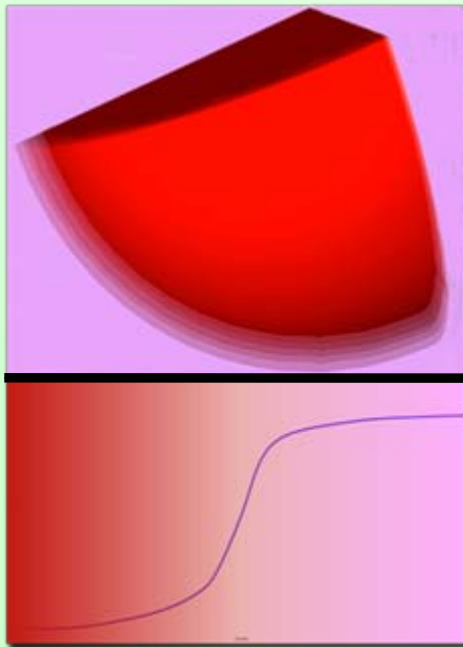
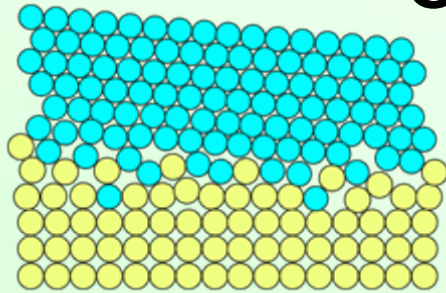
- Making a material, our first cut is to look for available materials that can deliver a set of specified properties.
 - We research new materials that are generally monolithic that will get us to those properties.
 - Composites are developed often to enhance some of those properties.
- Developing a “materials system”
 - I believe that we will further develop these capabilities in the 21st century to create real size integrated material parts for the specifications
 - Real size material
 - Interfacial engineering
 - Shapes matter
 - Creating new materials with
 - Integrated circuits are fine examples of this type of material design.



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Let's start at the interface as many of us learned it



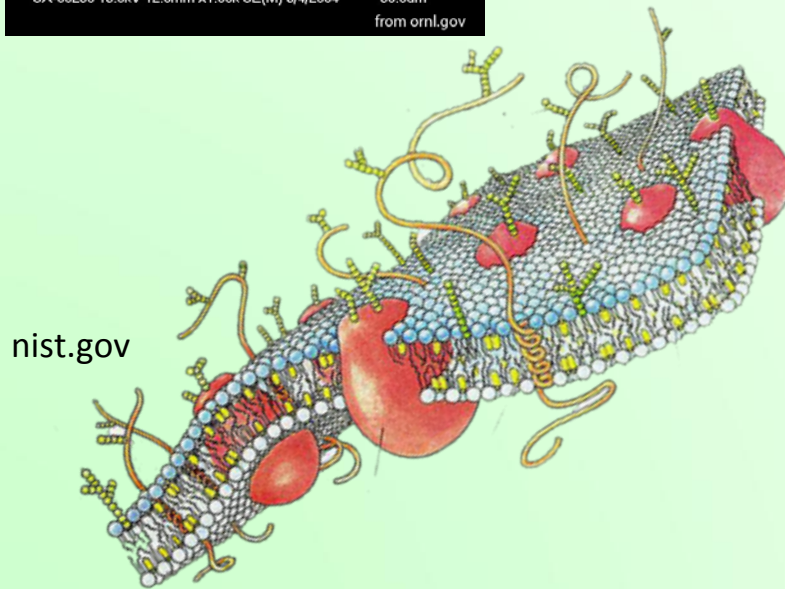
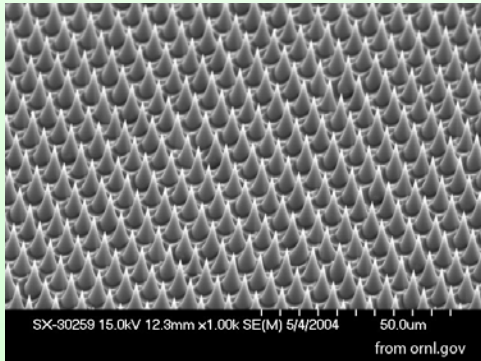
- Growing up in 1970s-1980s MS&E, we were aware that there were really two types of interfaces.
 - The mechanical interface exemplified in plasma spraying, undercutting and the like – not shown here.
 - The chemical bond where there was a diffusive layer that intermixed the two phases.
- In the past a chemical interface was based on disregistry, diffusion and amorphous material that sat between a couple of phases. The idea was to create a repetitive geometry that you wanted between the two phases.
- The issues of design – although they might not be simple to do – were to develop the chemical and mechanical properties of the interface and the sharpness (or thickness) of that boundary.



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Today's interface is in many ways revolutionary from those earlier ideas



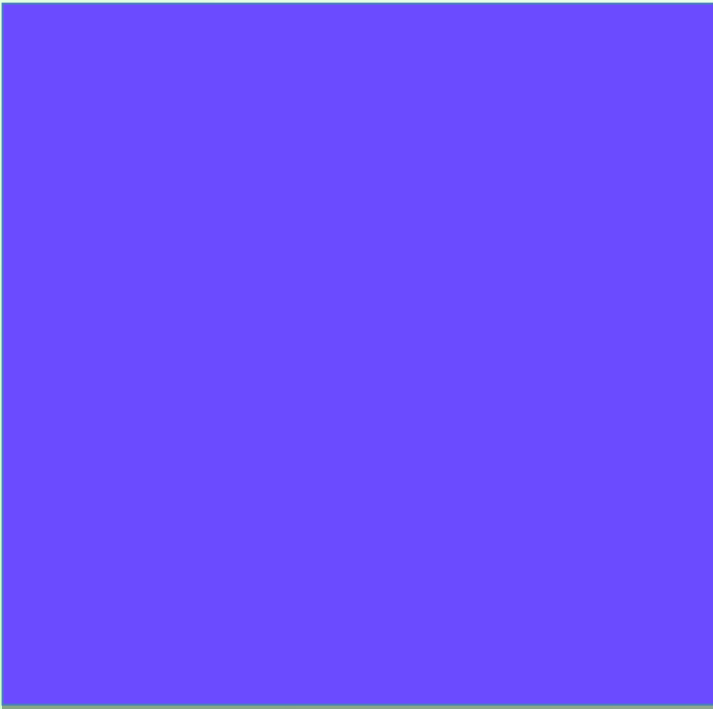
- Now we can begin to talk about engineering active useful materials process nanosized structures, devices or elements into the interface.
- Our materials start looking more like cells, tissues, organelles and organs than they do like the old 20th century basic material interface.
- We can start an era where a “material” is a system of materials banded together to create the properties.



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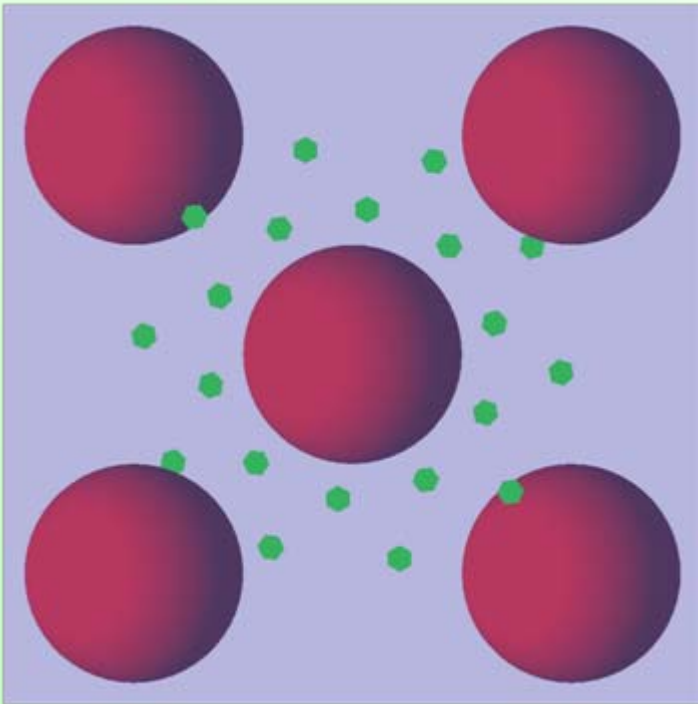
A new way to look at the term “materials system”



For the purpose of our discussion – the figure at the left is a simplified “part.” Yes, to us it looks like a square but I will argue that it is of real size and that is the shape that was desired for the service environment that this part needs to serve (certainly the shape easiest for me to play with in this talk).



A new way to look at the term “materials system”



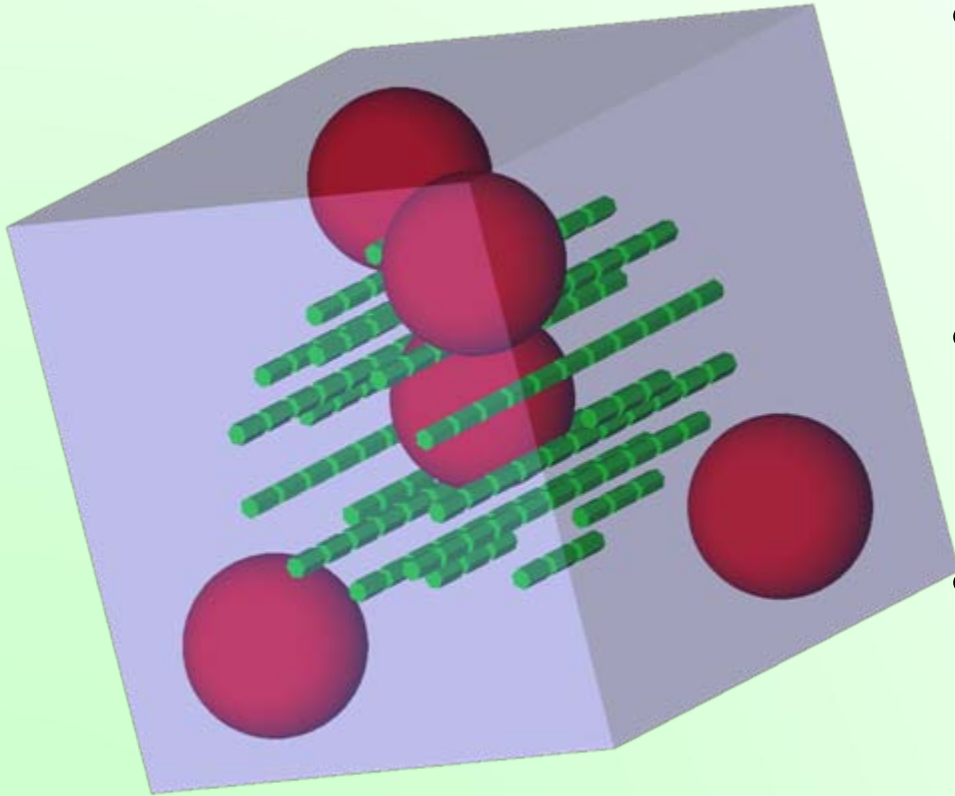
- If we could look into what seemed like a simple part, If we could see into the material itself
 - We would see that the structure is a designed structure.
 - As in any built composite, the internal structure is there to develop a set of internal properties.
 - Thermomechanical
 - Electrooptical
 - Information feedback
 - ????



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A new way to look at the term “materials system”



- Rotating the material part, we can see the intricacies of the design – at least on the mesocomposite scale.
- This however isn't the end of the engineering on this materials part.
- Add the discussion of the interface – and then the interrelationship between the interface and the phases – and – have you ever got a complex system!



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I think the “material system” is where we need to be

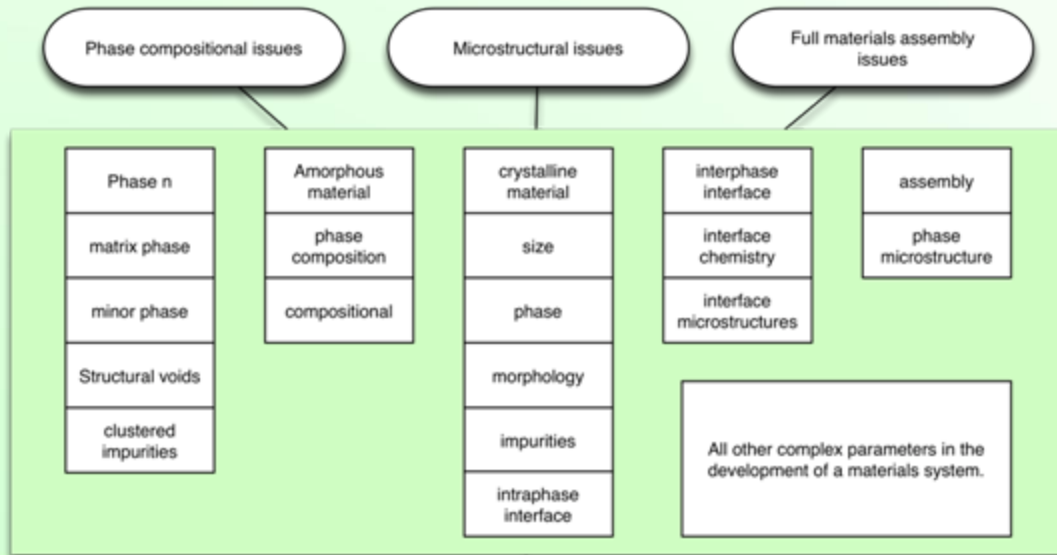
- The nuances of developing the “material systems” that we will be creating forces a very complex materials development activity.
- Looking at materials systems allows us to create innumerable new possibilities.



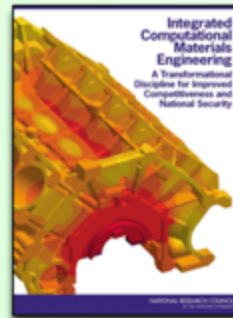
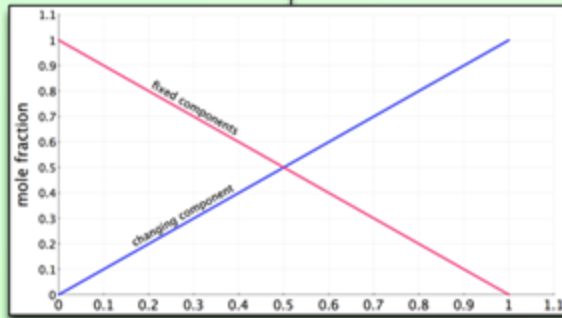
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There are many pieces to making a materials system.



- The nuances of developing the “material systems” that we will be creating forces a very complex materials development activity.
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To Conclude

- Materials in the 21st century
 - Will need to understand and overcome the limitations that are upon us or just over the hill.
 - Will have to develop materials systems that will fill the needs of the 21st century.
 - As for Materials Systems:
 - Materials will be developed as parts within a system
 - Materials will be built more along the lines of multilayer chips and biological cells and tissues.
 - There likely will be a matrix with minor phases which each have the potential to serve multipurpose functions.
 - We need to take hold of the opportunities that are available through needs and technologies
 - We need to look at our horizon and create our technologies from our dreams



Thank You



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