APEX EXPO IPC 2016

FORWARD THINKING

FOR TOMORROW'S TECHNOLOGY

This is an invited presentation

A paper from this speaker will not be provided for the Apex Expo™ 2016 Technical Conference

Approaches to Commercializing New Nano-Electronic Materials

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IncubatorWorks

Topics

- Nano-electronics potential
- Barriers to entry – and opportunities
- Examples
  - Nano-solder
  - Capacitor materials
  - Graphene
- Opportunities for rapid commercialization?

Nanoelectronics

- <10 nm semiconductor features - “More Moore”
- Semiconductor extension – “More than Moore” – molecular logic, biomimetic logic, nanotube / nanowire / graphene and other structures
- Fillers, coatings, adhesives, mold compounds, die attach, conductors, displays, lighting, anti-counterfeit taggants…

Nanotechnology and Nanomanufacturing

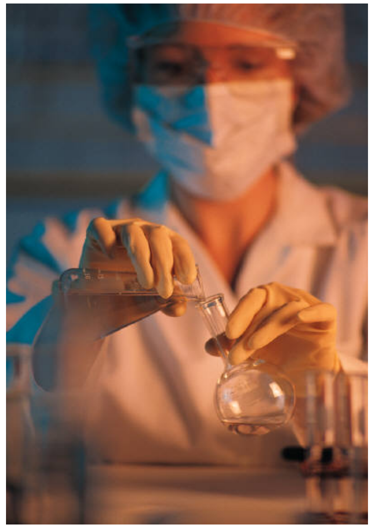
- Nanotechnology isn’t an industry
  - Wide diversity of applications, technologies and companies
  - Little in common between nano silver for solar, nano rare earths for phosphors, graphene for better battery electrodes, quantum dots for displays.

- Nanomanufacturing is a reality
  - Only visible in France and Belgium where there are compulsory reporting regulations.
  - Not visible or need to be disclosed elsewhere.
  - TSCA reform may change reporting in USA – currently only nano silver and carbon nanotubes?

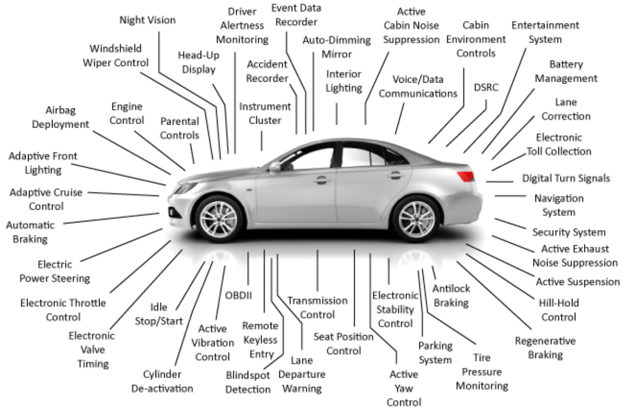
Market drivers

Source: pexels.com

- Better smaller faster cheaper thinner…
- Internet of Everything
- Telemedicine
- Cloud
- Security



Source: Monmouth Coffee Co.

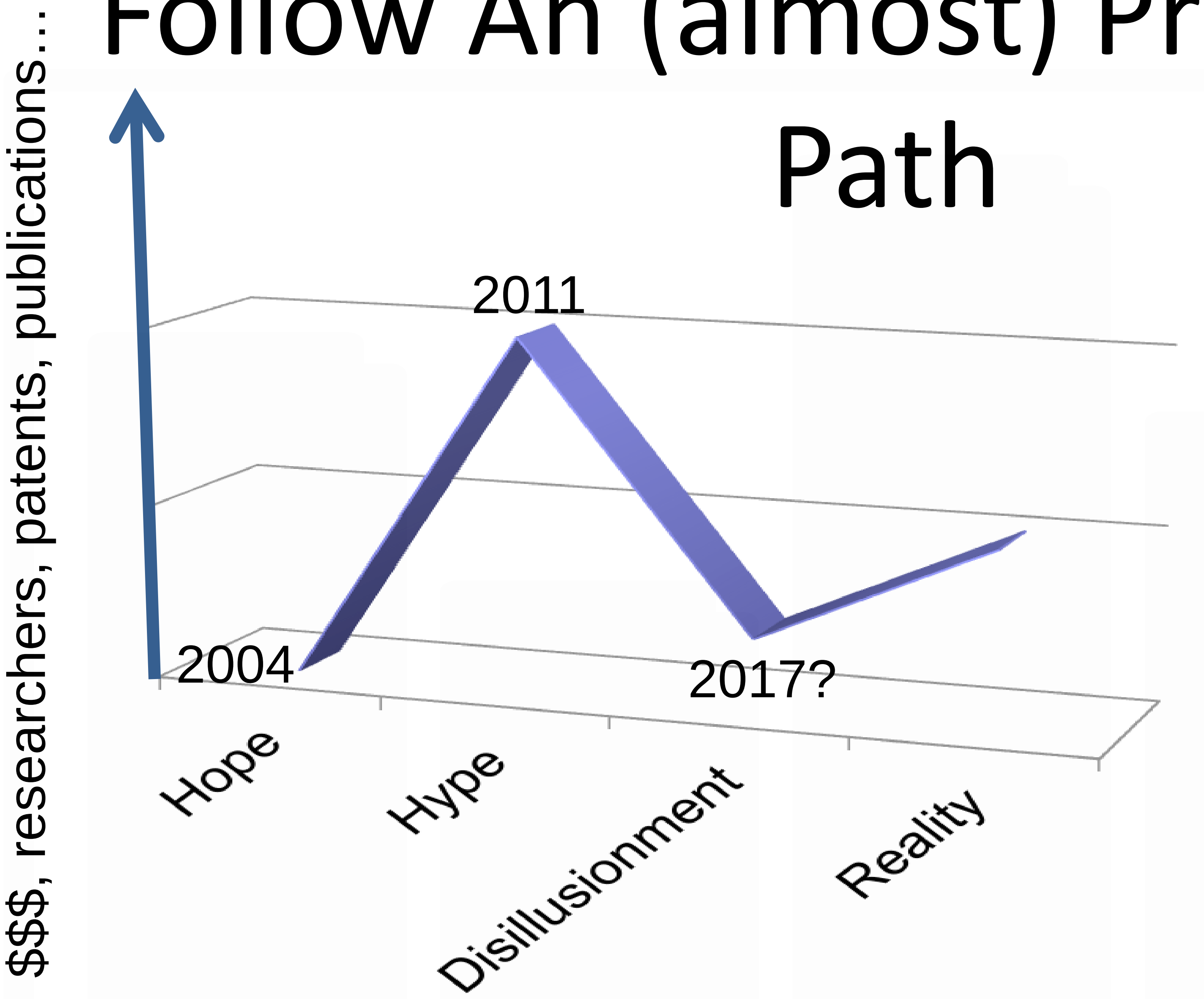


Source: Clemson

Lifecycles

- Product (smartphone) <= 1 year
- Semiconductor 18 months – 2 years - ?
- New material system - >15 years for lead-free solder!

High-profile New Technologies Follow An (almost) Predictable Path

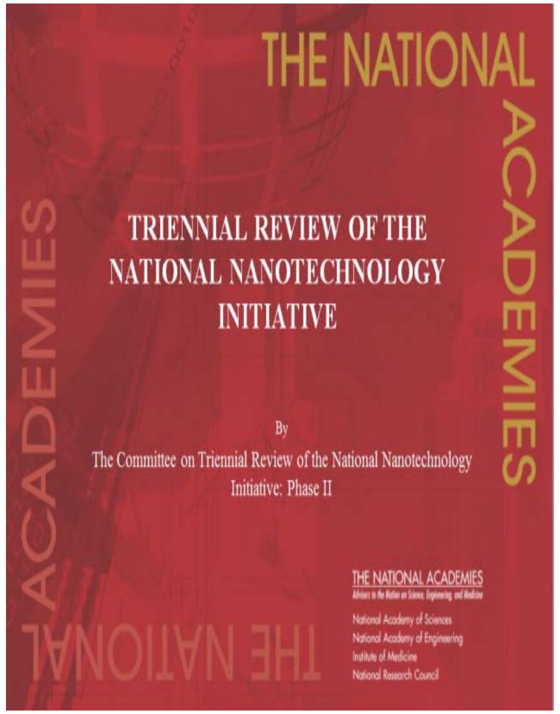


Why Does It Take So Long?

- Startup challenges, tech transfer, finance
- Multiple qualifications
  - New material => Formulator, EMS, OEM)
- Cost of qualification
- Increasing reliability requirements
  - Cell phone
  - Automotive
  - IoT
  - Military systems (B52 first flight…1952!)
- Timing: markets for products like MEMS and Gorilla Glass didn’t exist in the 1960’s!

Minimizing Reliability Risk

- Lowest risk products are
  - "Drop in" solutions e.g. nano coated stencils
  - Presented by vendors that understand the complexity of customer
  - Evaluated by consortia e.g. iNEMI, AREA, HDPUG
- It is challenging for small or start-up companies to compete, and most need to partner with established suppliers
- Disconnect – most of the NNI nano funding has gone to universities, government labs and small businesses
  - Large companies generally do not want to license from universities – too long to market?
  - Licensing policies can be inconsistent under Bayh-Dole (NAS Triennial Review)
  - The business climate is really tough for small businesses to get to the size where they can partner with larger businesses
    - Sequestration, diversion of angel funding to software, lack of venture funding, few small IPOs…


THE NATIONAL ACADEMIES

TRIENNIAL REVIEW OF THE NATIONAL NANOTECHNOLOGY INITIATIVE

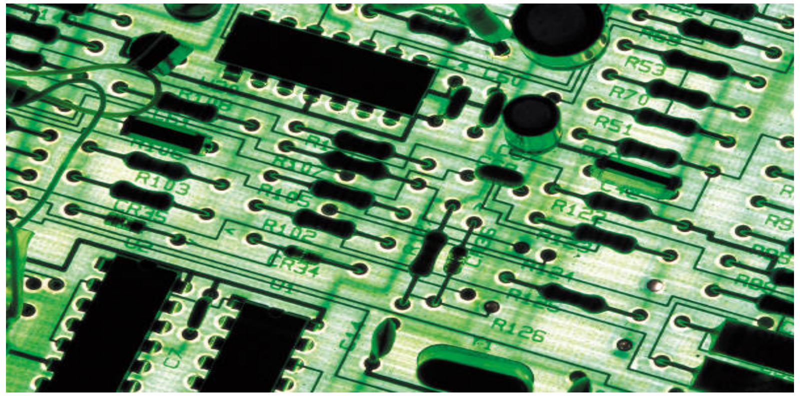
By

The Committee on Triennial Review of the National Nanotechnology Initiative: Phase II

THE NATIONAL ACADEMIES

Vitamin or Painkiller?

- Vitamin
  - Nanotex pants
  - Auto polish
- Painkiller
  - Anti-aging cream (?)
  - MRI image enhancement
  - Drug delivery
  - Stencil coatings

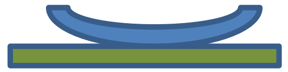


Nano Solder

- Original work carried out by iNEMI 10 years ago
- Subsequent work by other companies/organizations including Purdue, UMass, TPF, NanoDynamics…
- Advantage
  - Lower melting point due to metal particle size
- Challenges
  - Rapid oxidation of tin
  - Joint is sintered not melted; has porosity
  - Rework is at a higher temperature than joint formation
- Competition
  - Lower temperatures being sought through alloying e.g. Bi alloys (feasible in lead-free locations)
- Status
  - Not widely commercialized…

Why Reduce Process Temperature?

- Expansion mismatch – warping

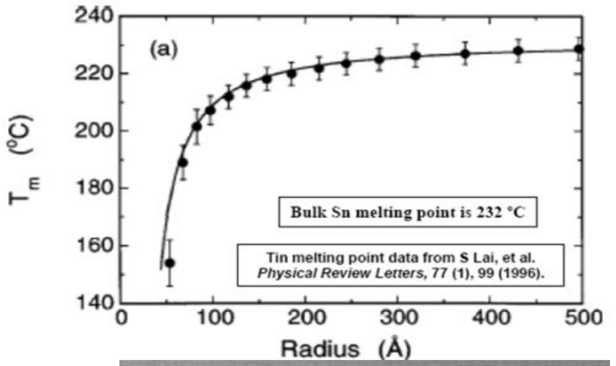


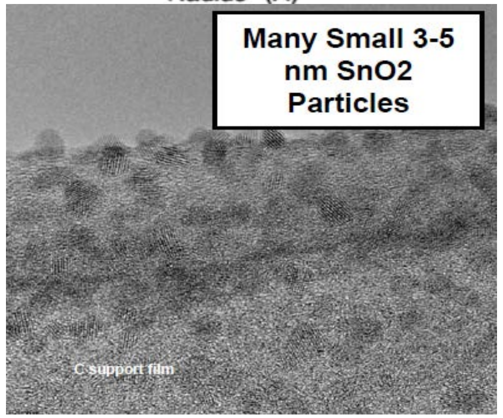
- Component damage through diffusion and other phenomena at high temperature
- Dynamic thermal transfer rates during reflow mean small components may be overheated, large components under-heated
- Energy costs

Melting points – Sn 232^{o}C, Ag 961^{o}C, Cu 1084^{o}C

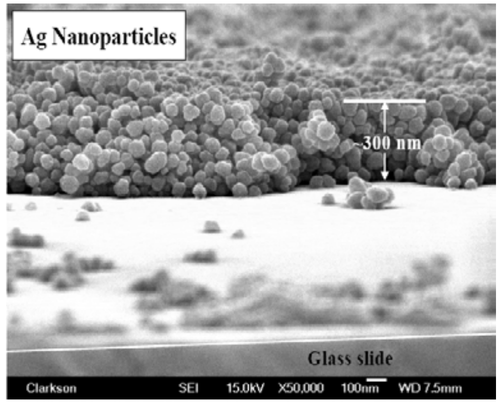
Good News and Bad News

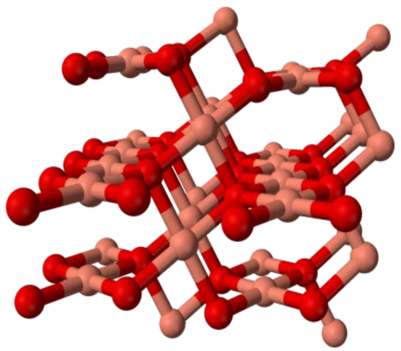
- The melting point indeed reduced by a large amount – 15nm Sn 183°C
  - But…Sn oxidizes very rapidly at room temperature
- Silver can be processed below 200°C
  - But…forms a sintered rather than melted material (as grains join the melting temperature goes up)
- Copper can be processed at 200°C
  - But… needs extreme care to prevent oxidation





Ref: Purdue / NanoDynamics

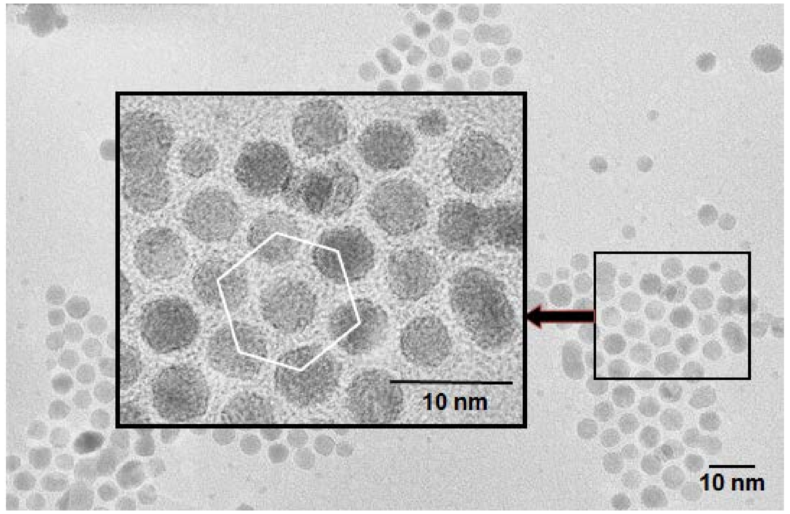




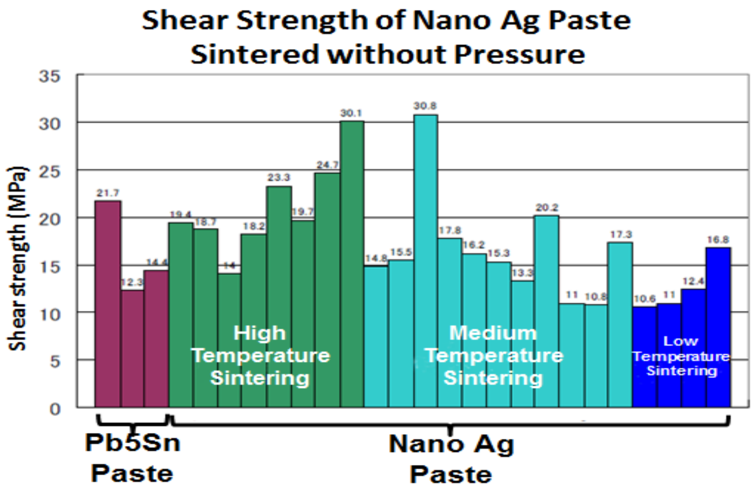
(CuO -Creative Commons)

Silver Die Attach Opportunity

- Capping control design is closely managed using n-dodecanol



- And performance is comparable to high-lead die attach



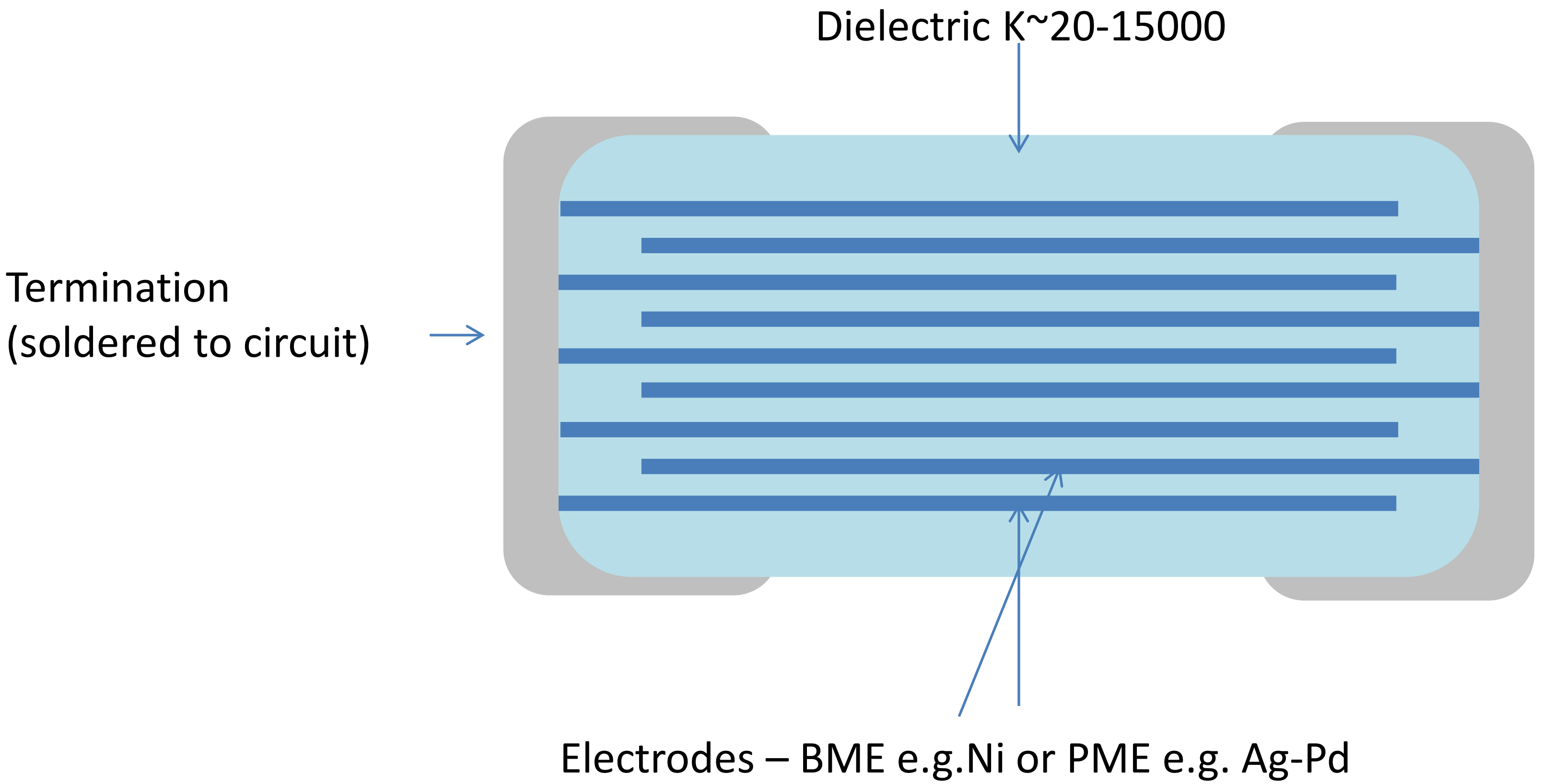
Reference: From "A Nano Silver Replacement for High Lead Solders in Semiconductor Junctions"
Sweatman, Nishimura & Komatsu, SMTA Pan-Pac 2013
Nihon Superior

Nano Capacitor Materials

- Ceramic and metal ink particles have been approaching nano size for some years ~100-200nm
- New innovation – “Virtual Nano Electrode” – self-assembled nano-sized metal particles near the electrode since 2009
- Advantage
  - Can increase capacitance 5X
  - Uses current manufacturing infrastructure
- Challenge
  - Tuning the process and improving yields
- Competition
  - No clear competition at present
- Status
  - Raising funds for process development

Multilayer Ceramic Capacitor

C (energy storage) $\propto$ K (dielectric constant) A (electrode area)/T(electrode separation)



The Challenge

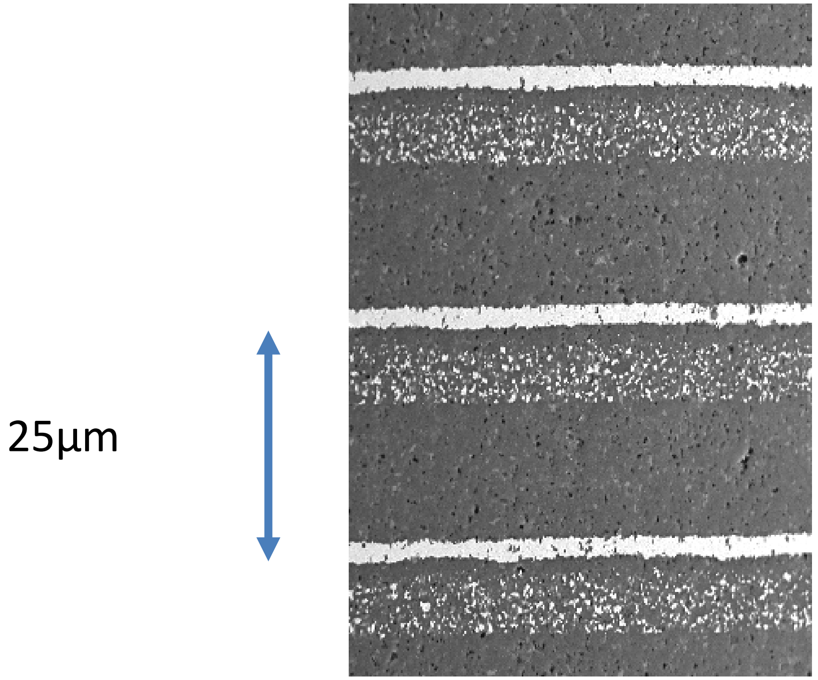
- How to use a non-nano approach to give the benefits of nano without the drawbacks
  - Use existing materials
  - Use existing equipment
  - Self-assemble a functional nanostructure that gives the desired properties by improving, K, A or T?

- One Approach – use a coated layer under the electrode print to self-assemble a dispersed nano electrode from a non-nano precursor, effectively increasing A (electrode area) whilst using existing dielectrics and electrode materials
  - Non-nano gives ready printability with existing ink vehicles

Demonstration

- Used a high silver low fire PME system as proof of concept
- Metal coated material printed under electrode
- Measured “Dielectric Constant” 113
- Normal Dielectric Constant 23
- Dielectric loss equivalent to conventional parts

- Mechanism – self-assembled
  - “Virtual nano electrode”
  - Did not behave like a floating electrode
  - Did not behave like uniformly dispersed metal

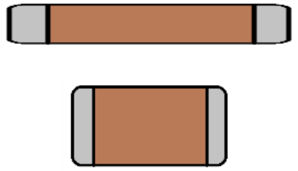


What Could 5 times the Effective Capacitance Do For Designers?

A normal capacitor stores a charge e-

An advanced capacitor the same size stores a charge 5e-

Higher Power



An advanced capacitor 1/5 the number of layers stores a charge e-

Smaller, Thinner

An advanced normal size capacitor with 1/5 the metals content stores a charge e-

Lower Metals Cost

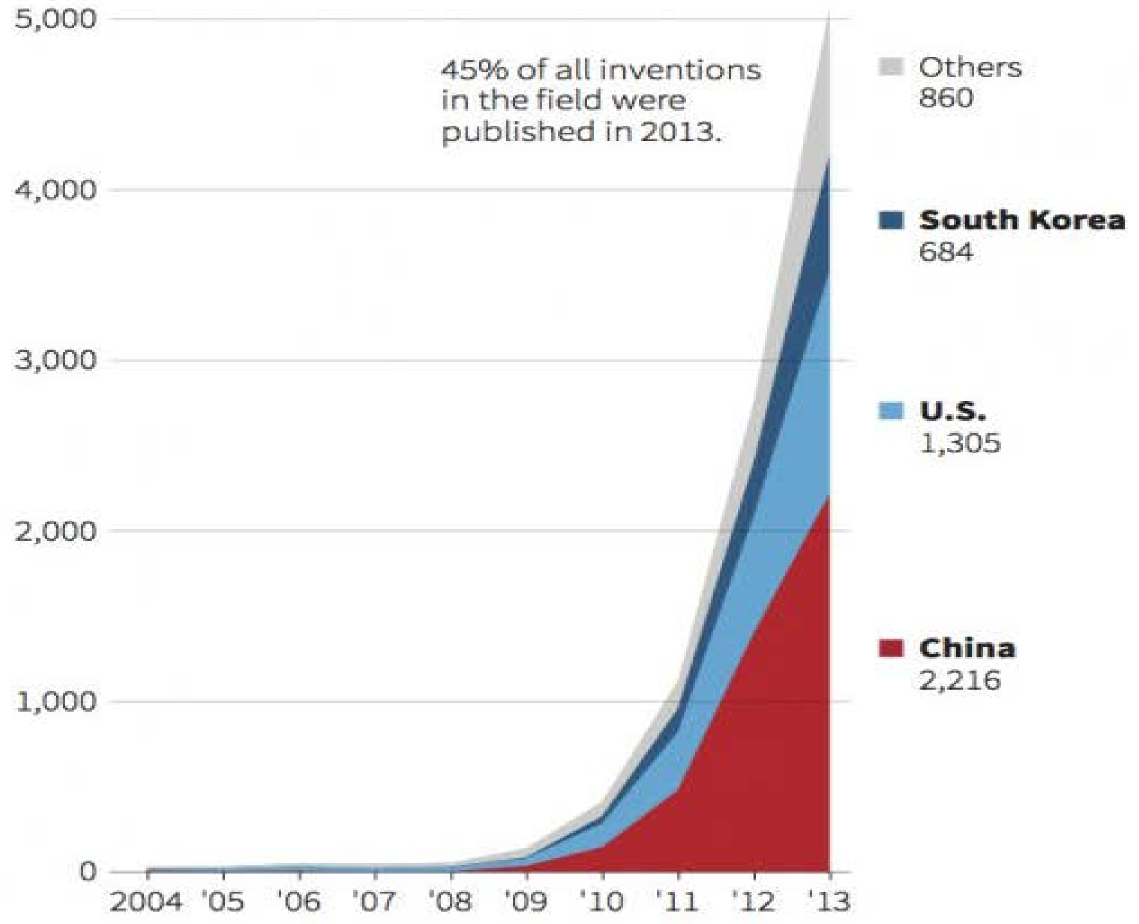
Graphene Nanoribbons

- Graphene is a conductor but in nano ribbons quantum confinement produces a controllable band gap
- Fabrication technology initially developed at University of Utah ~ 10 years ago
- Advantage
  - Small and potentially low cost front end bandpass filters
  - Uses current manufacturing infrastructure
  - Terahertz capable for communications and imaging
- Challenges
  - Designing and fabricating demonstration parts
- Competition
  - Compound semiconductors
- Status
  - Raising funds for demonstration parts

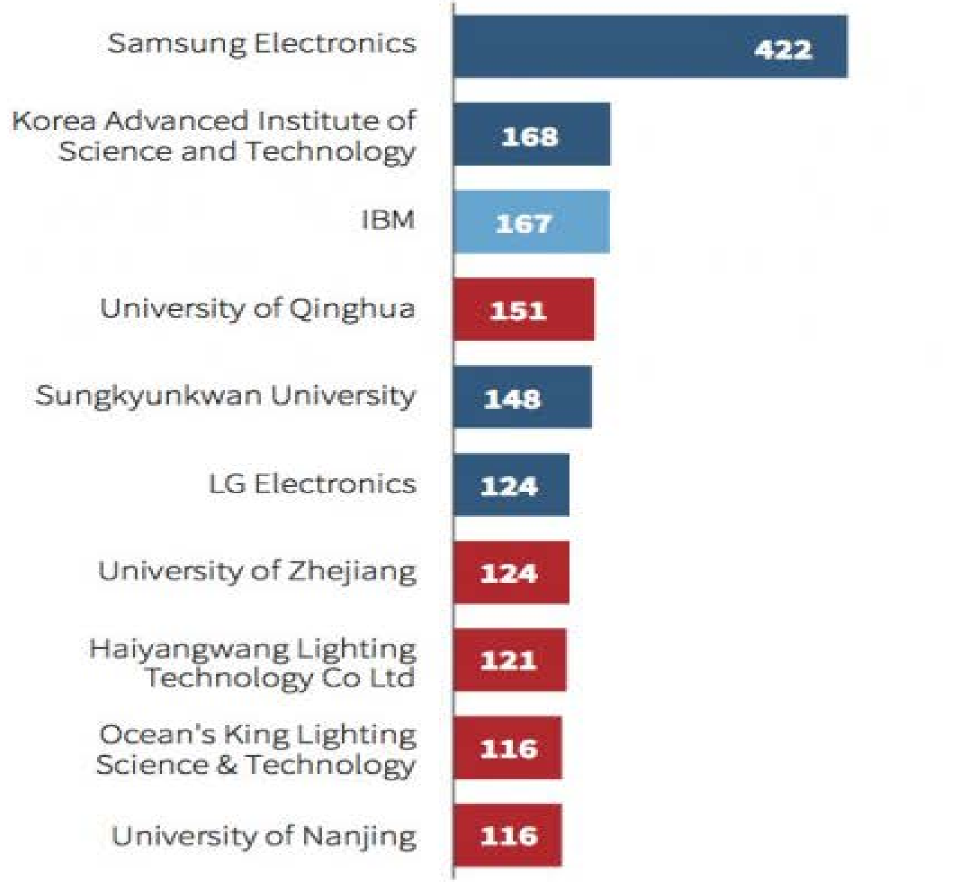
Graphene patents

Analysis of inventions involving the manufacture or application of graphene shows dramatic growth over the last decade from just 33 inventions described in published patents in 2004 to over 5,000 inventions last year

Countries with the most graphene inventions



Top ten companies/institutions with the most patents



- Graphene, a one-atom thick layer of graphite, is stronger and harder than diamond, yet can be stretched by a quarter of its length like rubber.
- First mentioned in a study in 1987, it was isolated in a stable free form in Manchester, England in 2004.
- Graphene inventions apply to technologies such as touch screen displays, lithium ion batteries, fuel cells, mobile phones, LED displays, and electronic components in general.

Source: Reuters

C. Inton, 29/04/2014

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GLOBAL GRAPHENE MARKET

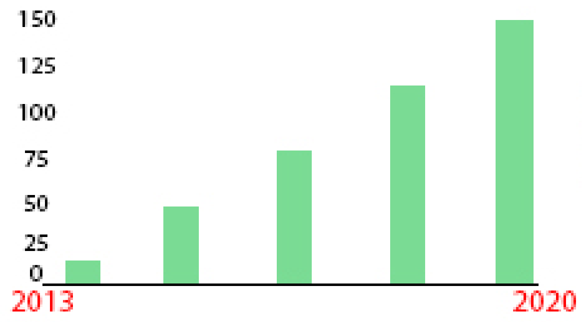
Size & Forcast,

(2013-2020)

For More Details See Table Of Contents

GLOBAL GRAPHENE MARKET

Market is Expected to Reach $149.1 Million in 2020



Growing At a CAGR of 44.0% (2014-2020)

GLOBAL GRAPHENE MARKET, BY TYPE

- Mono-layer & Bi-layer graphene
- Few Layer Graphene
- Graphene Oxide
- Graphene Nano Platelets
- Others

GLOBAL GRAPHENE MARKET, BY GEOGRAPHY

ASIA-PACIFIC, EUROPE, LAMEA

NORTH AMERICA

Highest Revenue Generating Geography $43.4 Million by 2020

GRAPHENE MARKET BY APPLICATION

- In Energy
- Aerospace
- Biomedical and life sciences
- Automotive
- Coatings
- Composites
- Defense
- Sensors
- Electronics
- Others

GLOBAL GRAPHENE MARKET, DYNAMICS

Drivers

- Rapid increase in graphene producers
- Growing adoption of graphene in various sectors
- Increased focus on r&d

Restraints

- Absence of band gap
- Susceptibility to oxidative environments
- Hurdles in volume production

Source: www. alliedmarketresearch.com

FORWARD THINKING FOR TOMORROW'S TECHNOLOGY

Reference: Lux Research

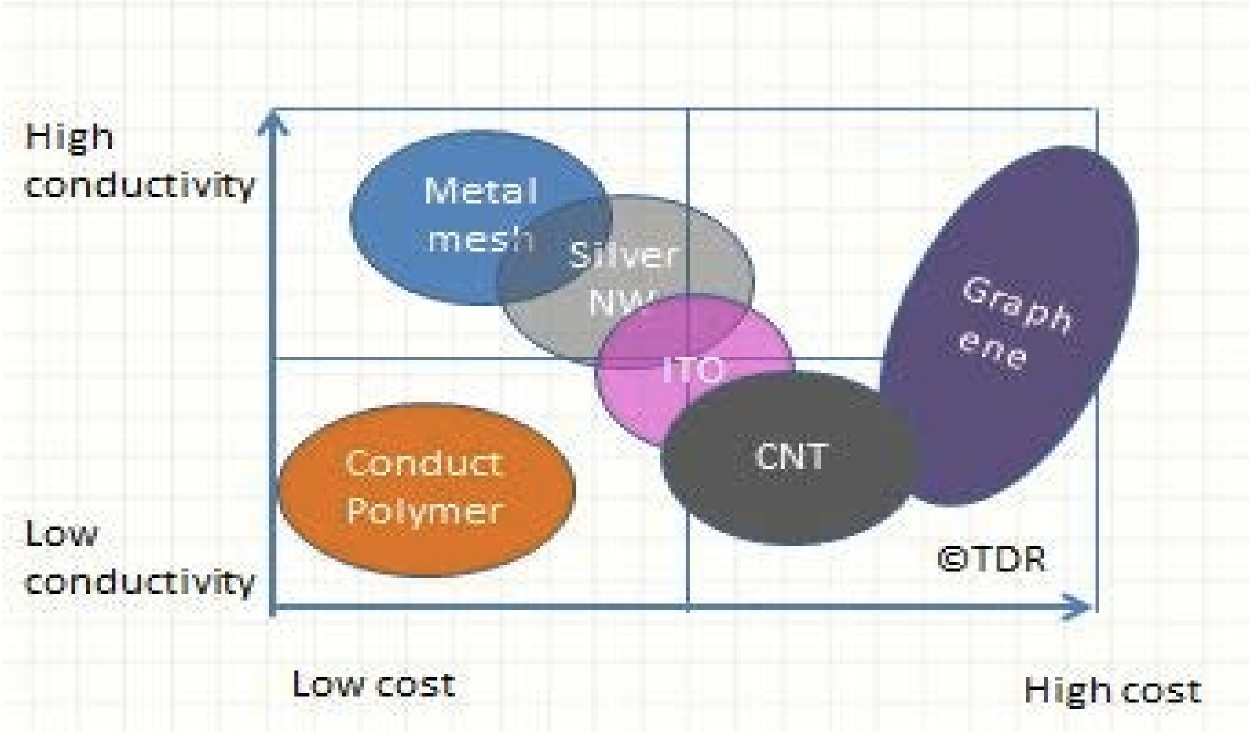
Is Graphene the Next Silicon … Or Just the Next Carbon Nanotube?

December 17, 2012 | State of the Market Report

Graphene has been touted as the next wunderkind material for the better part of this millennium, due to its exceptional mechanical, electronic, and thermal properties. However, one look at the rocky history of carbon nanotubes shows that a research and patent boom along with impressive technical performance is far from a guarantee of commercial success, as major challenges like high costs, processing issues, and competing emerging material classes loom large. What's more, a slew of recent capacity expansion announcements threaten to throw the space into oversupply.

The Original “Killer App” - ITO Replacement - Painkiller?

- ITO has not been replaced yet!
  - Existing infrastructure
  - No shortage
  - Cost
  - New competitors
  - Pain is not so bad…
- Not every painkiller works



Source: www.touchdisplayresearch.com

Challenges

- It’s a new material – hit mainstream science in 2004 (although predicted and made inadvertently much earlier)
- Biggest competitor – carbon nanotubes
- Patent land grab…
- It’s a conductor.
  - Good news – ballistic electron mobility
  - Bad news – range in microns
  - Bad news – good, lower cost conductors exist
- It’s a solution looking for problems (as with any new material) 1/2

Opportunities

- Lots of ways to make graphene from carbon based systems
- Potentially low cost
- CVD material does not have particles (c.f. nanotubes) – wafer fab friendly
- Graphene can be used to develop magnetic, optical and semiconductor properties in a number of ways

Nanoribbon Potential Applications

GHz devices

•Potential integration with IC or package, lower cost, smaller size, higher performance

THz devices

•Enable short range data transfer – vehicle area networks, room area networks, body area networks at 100x the data rate of Wi-Fi

Far infrared

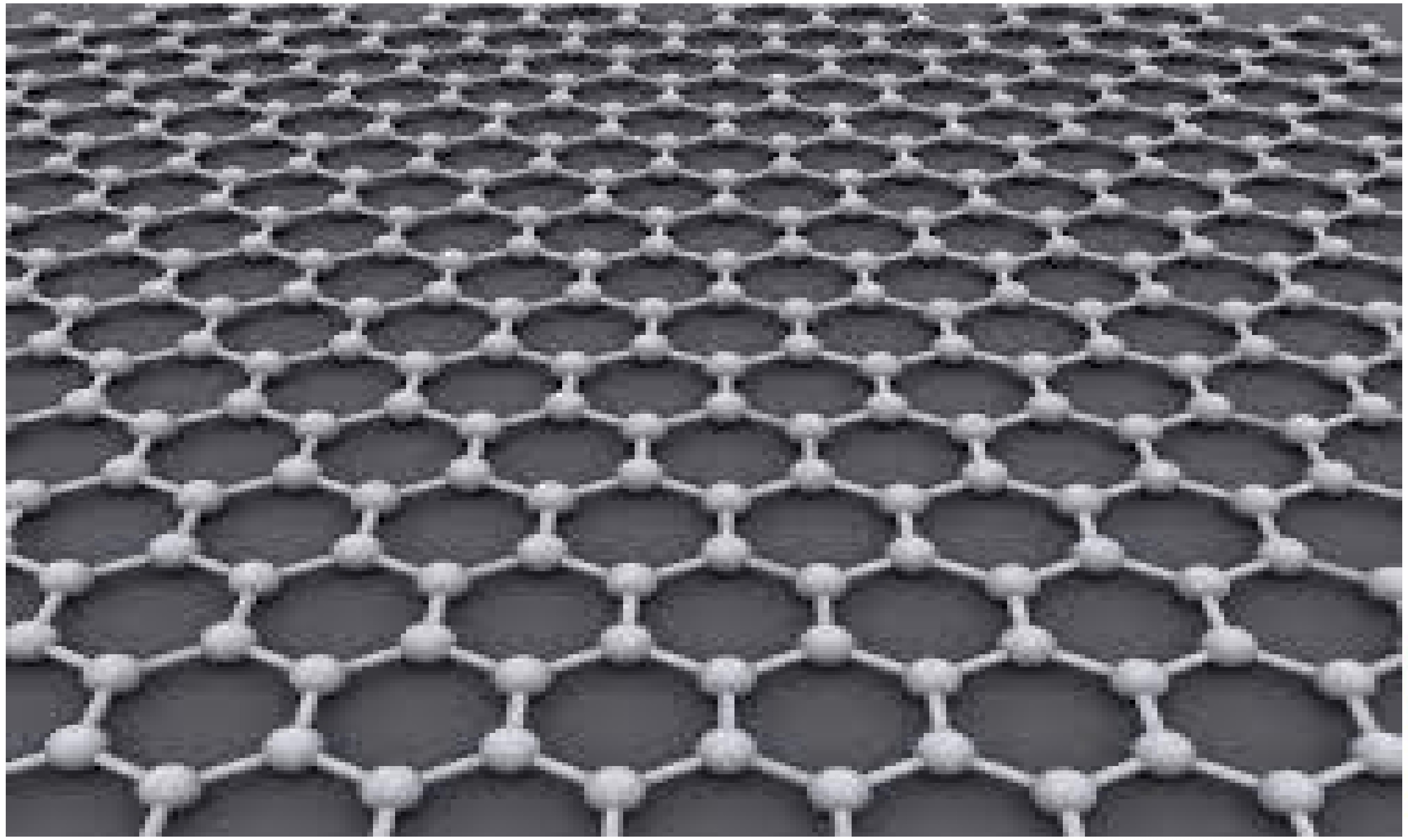
•Military and medical imaging

Longer term

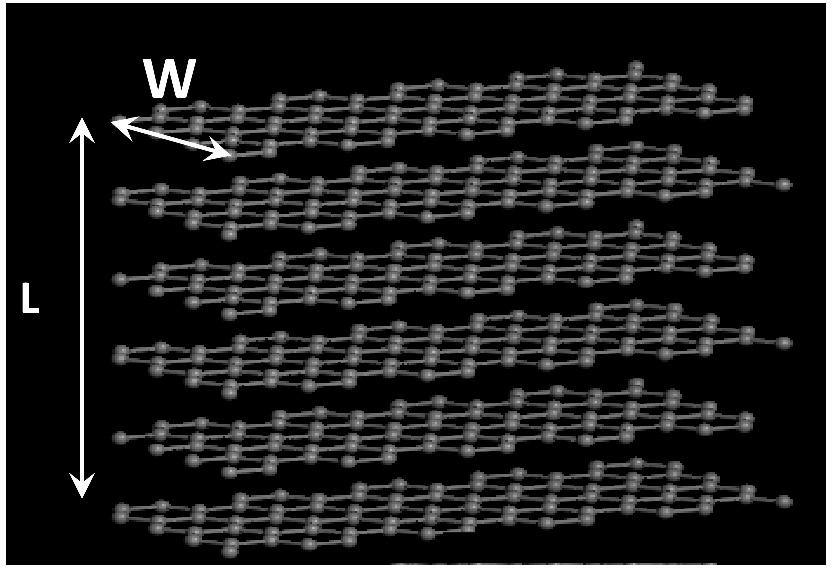
•Bio sensors

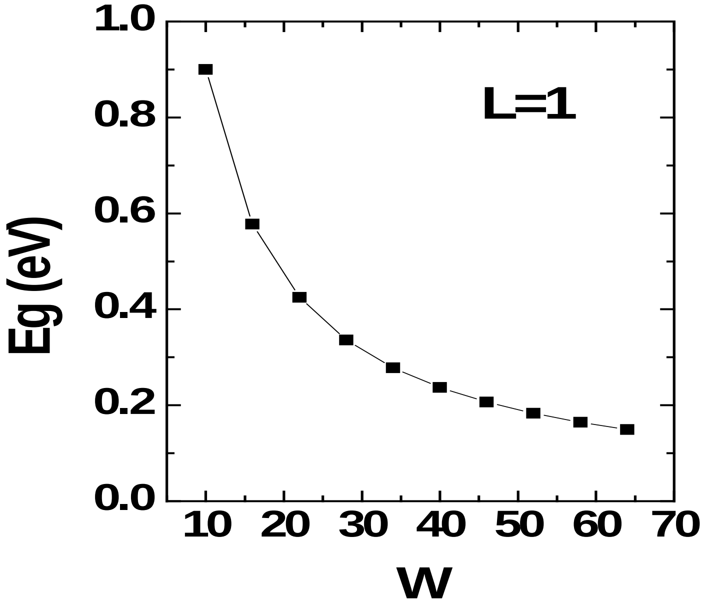
•Solar Cells

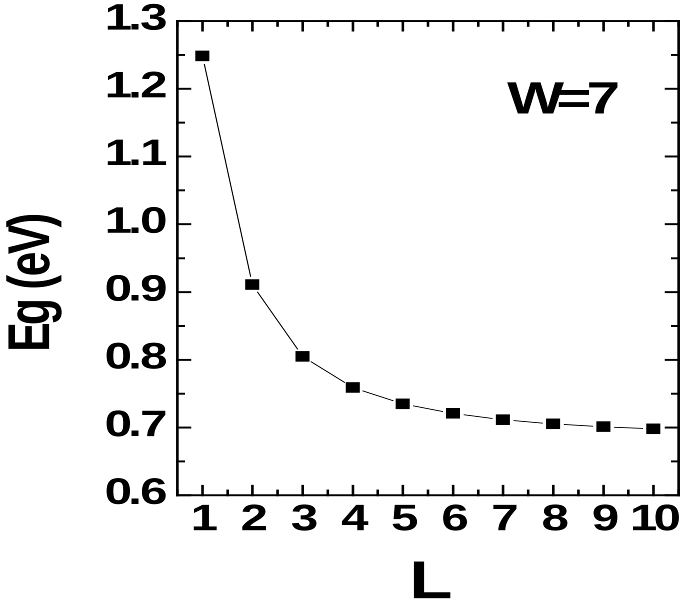
•LED



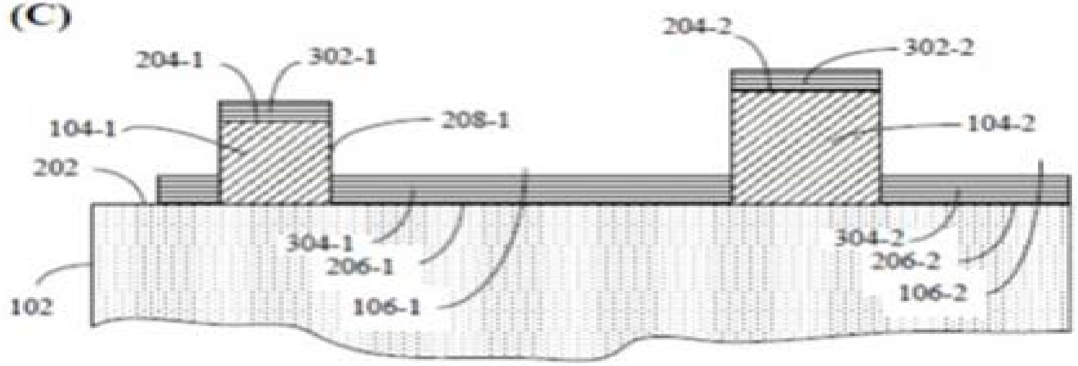
Band Gap of Nanopatterned Graphene







Topography Isolation



Stacked bandgaps

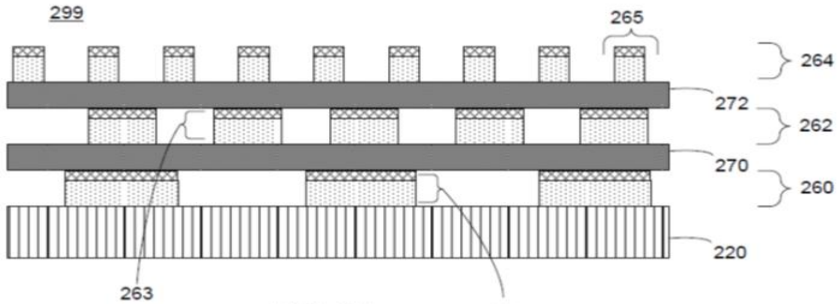


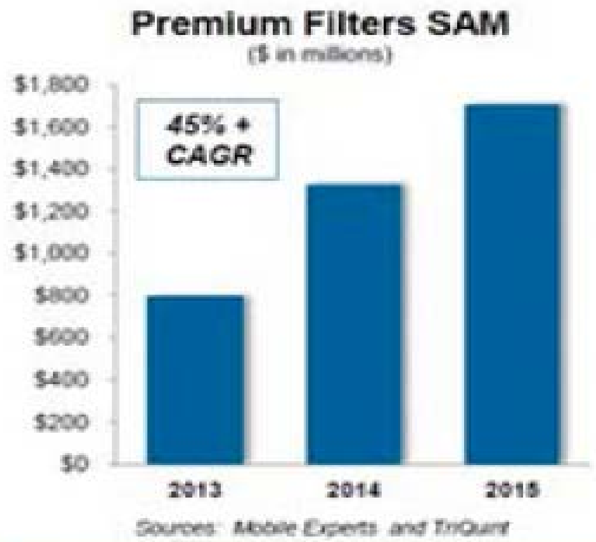
FIG. 2J

Reference: (Solan LLC)

Current PAIN Point – Front End Bandpass Filters

Exhibit 12

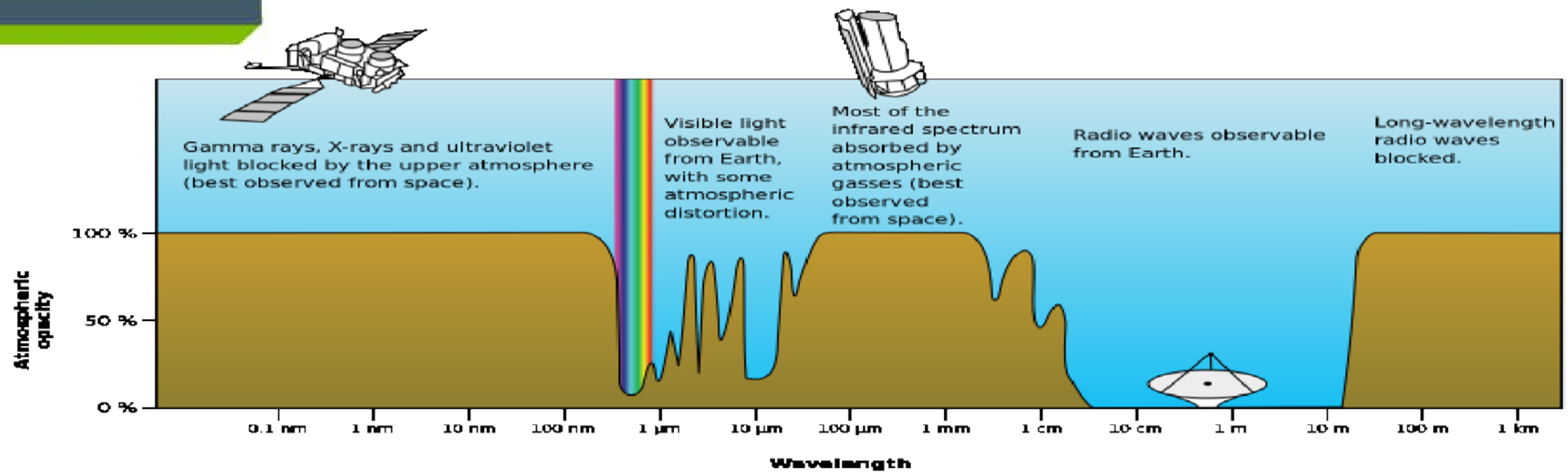
Filter content in different segments of smartphones



	Typical 3G	Regional LTE	Global Roaming LTE
SAW Filters	$1.25	$2.25	$3.00
BAW Filters	$0.00	$1.25	$3.50
Power Amplifiers	$1.25	$1.75	$2.00
Switches / ASMs	$0.75	$0.75	$1.00
Wi-Fi	$0.50	$1.00	$1.00
Total RF Content	**$3.75**	**$7.00**	**$10.50 +**

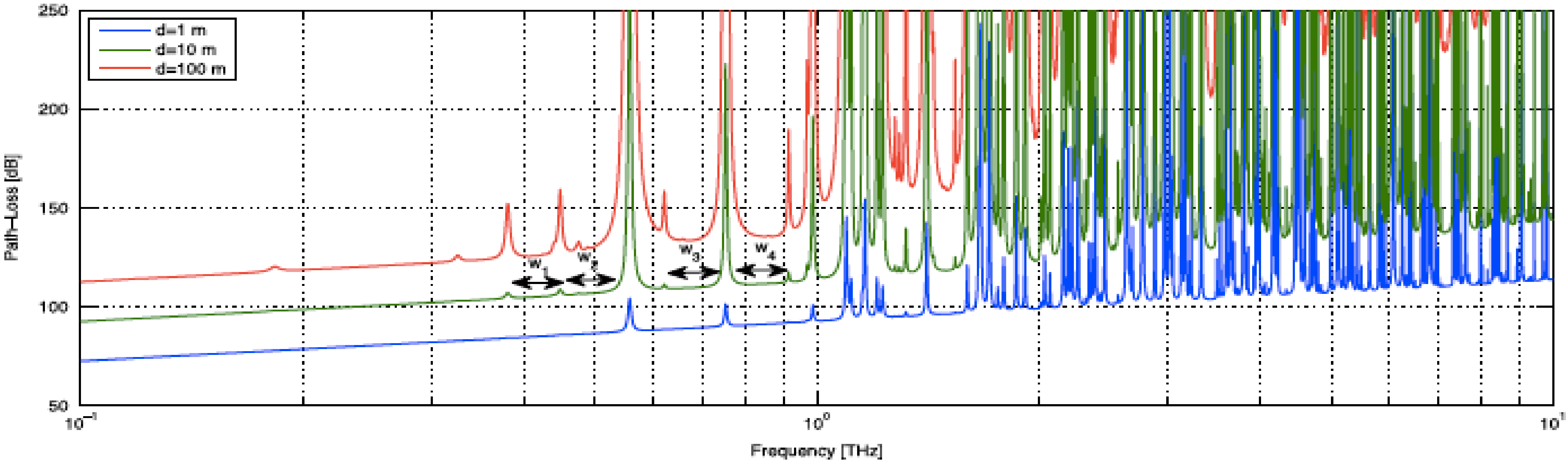
Source: TriQuint Semiconductor, Morgan Stanley Research

Atmospheric Attenuation in Unlicensed Bands

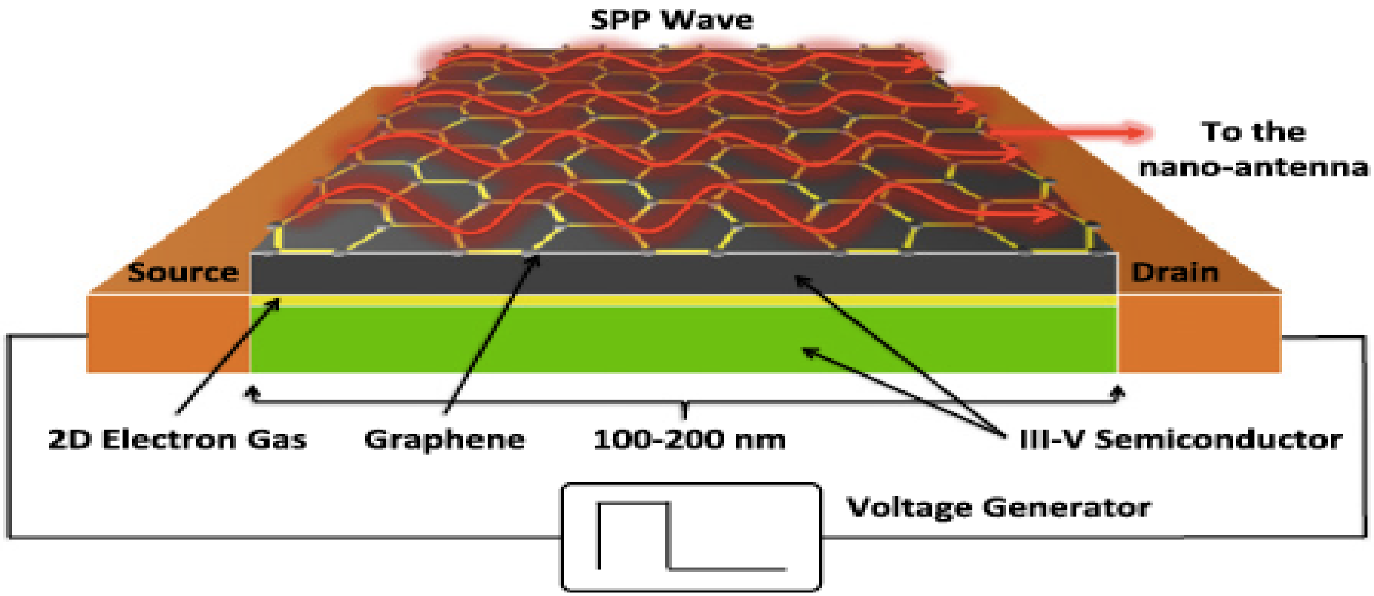


Source: Creative Commons

I.F. Akyildiz et al. / Physical Communication 12 (2014) 16–32



Making and Integrating Useful Devices with Graphene



Plasmonic Transceiver (Akyildiz)

SPP = Surface plasmon polariton at the interface of a conductor and air
Charge motion in the conductor and EM waves in air

Conclusions

- Most rapid success
  - "Painkiller Need"
    - Not a solution looking for problems…
  - Demo parts available early
  - Shared qualification process e.g. iNEMI reduces time and cost
  - In a market where extended qualification isn't needed
  - University or startup links with a channel partner who has industry credibility

Thank You!

- Acknowledgements
  - Solder – iNEMI, Purdue
  - Capacitors – Apricot Materials Technology
  - Graphene – Solan
  - Colleagues at IncubatorWorks and throughout the industry

- Contact
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