

The Reliability of Wearable Electronics

2015

권형안/(주)엣슬리트엣지

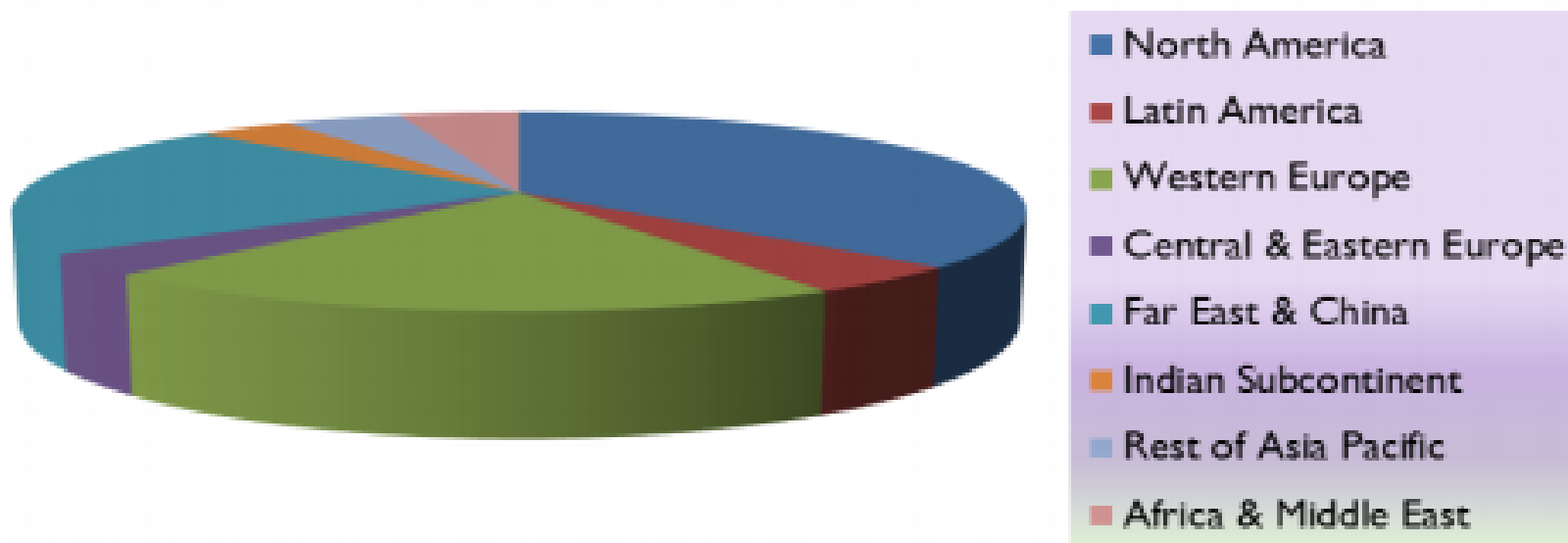
Sound Familiar?



www.zitscomics.com

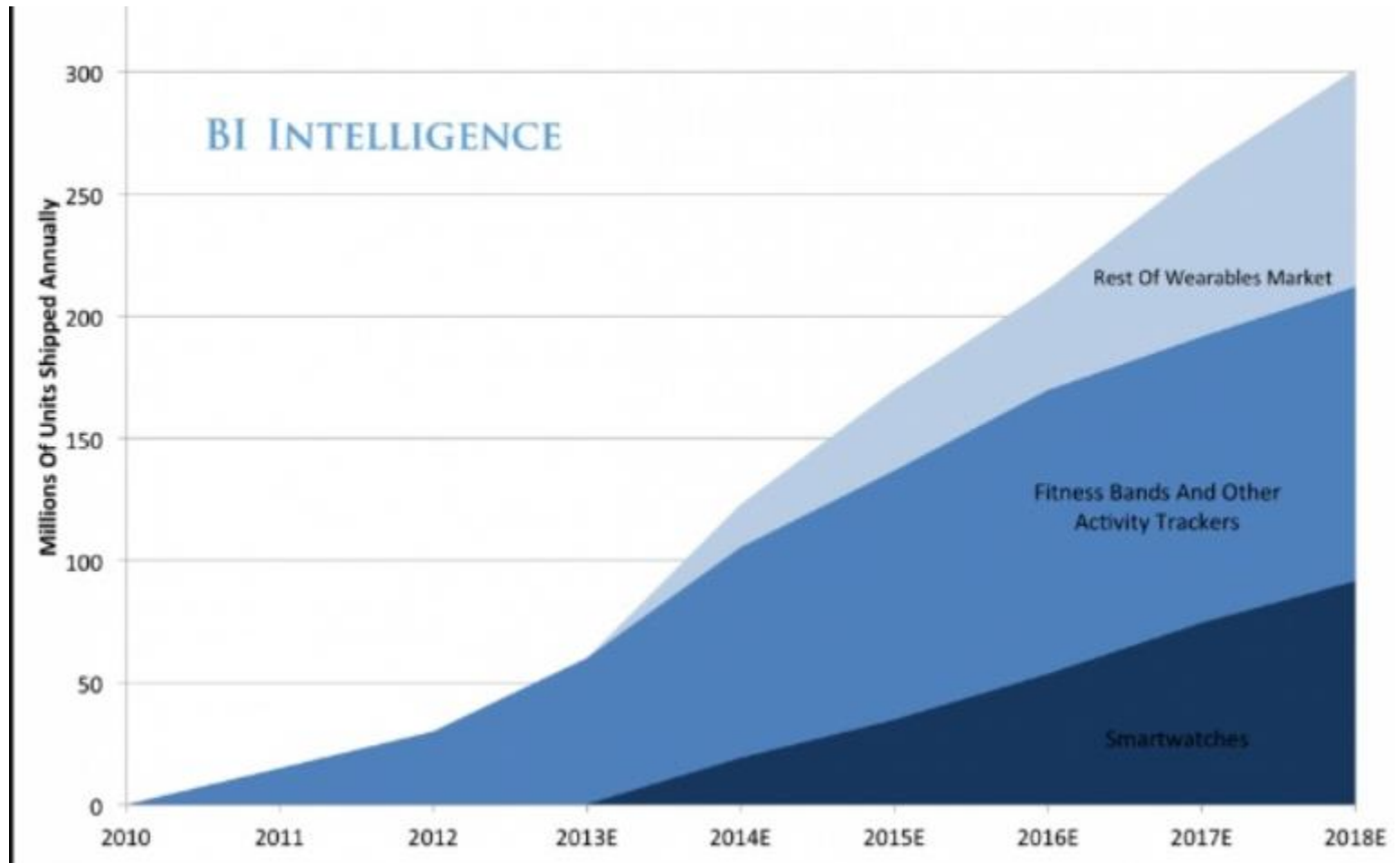
Wearable Electronics are hot, hot, hot!

**Figure: Global Smart Wearables Hardware Revenue (\$m)
Split by 8 Key Regions 2018: \$19 Billion**



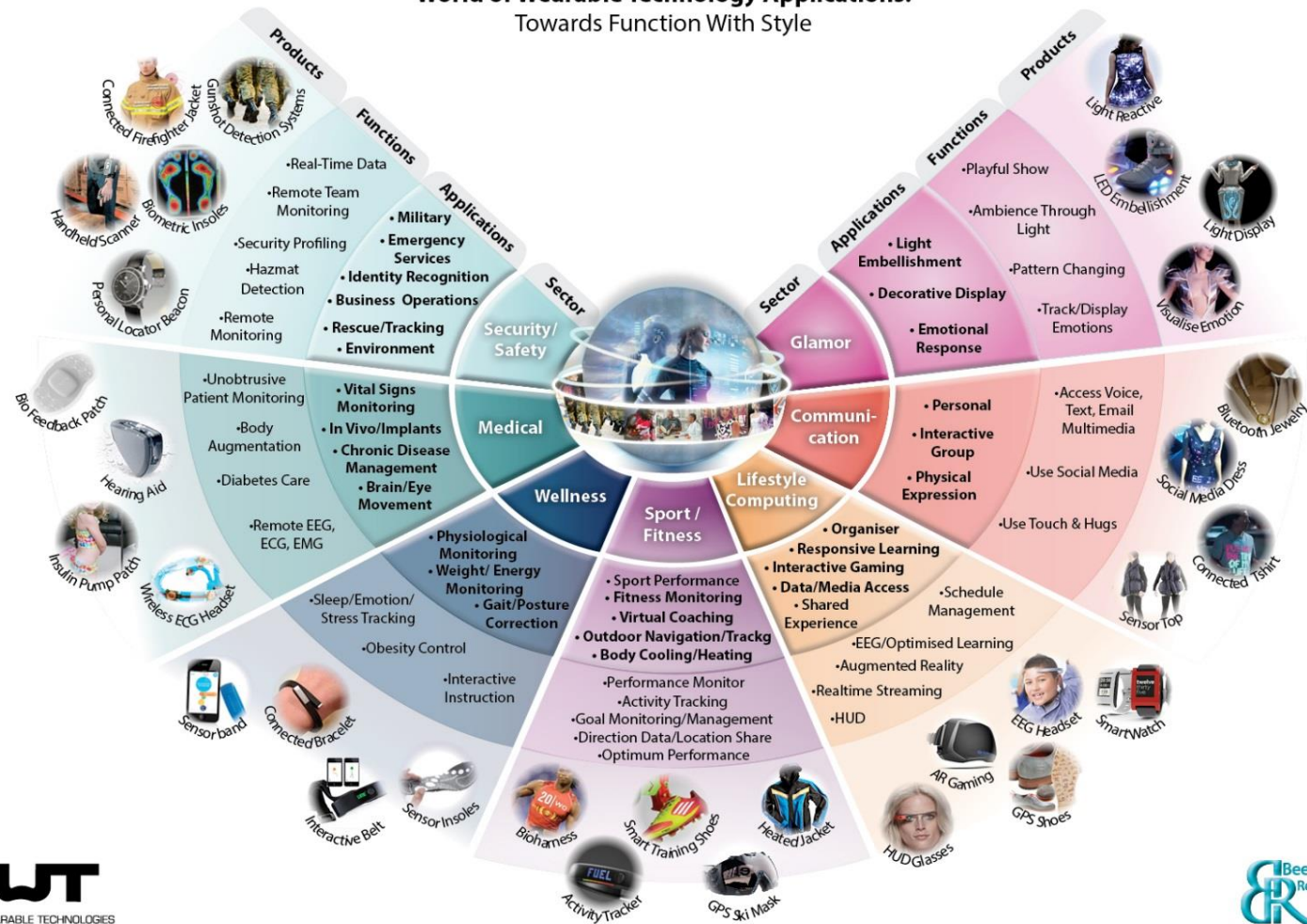
Source: Juniper Research

Wearables Market



Wearable Electronics Applications

World of Wearable Technology Applications: Towards Function With Style



Apple Watch



Expect 40-42 million units to be sold in 2015

Why????

The typical iPhone user looks at his phone 110 times a day.

“Behavioral Shift”

100 apps at a cost of \$350

Other apps: Pinterest, city mapper, BMW, Honeywell (house temp), Lutron (home management), Nike, American Airlines, Starwood Hotels

Apple's Not Alone



ConnecteDevice [Cookoo](#)



I'm [Watch](#)



Meta [SmartWatch](#)



Qualcomm [Tog](#)



Magellan [Echo](#)



Sony [LiveView](#)



Omate [TrueSmart](#)



Neptune [Pine](#)



Martian [SmartWatch](#)



Samsung [Galaxy Gear Watch](#)



Pebble [Steel](#)

"Even though wearables are relatively new in terms of market maturity, it is clear that the market, for example the smart watch in particular, will be – as per smartphones – a somewhat crowded affair." – Nitin Bhas, Juniper Research ([link](#))

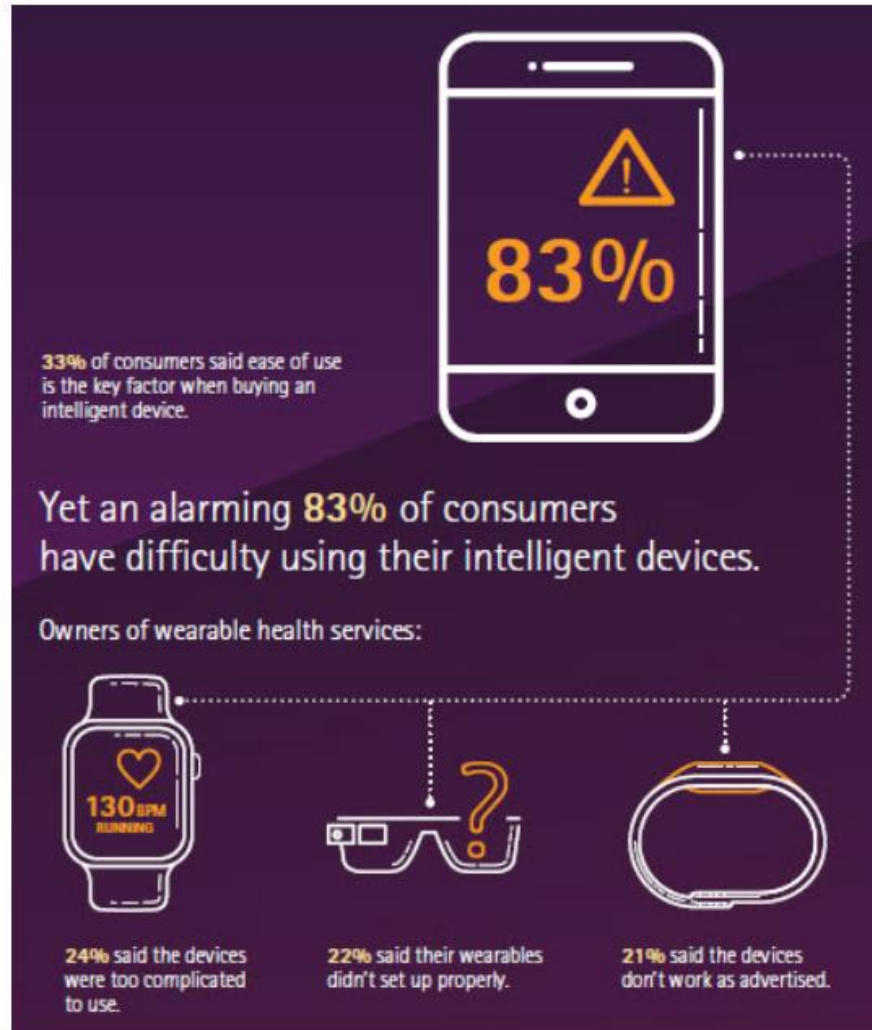


FILIP [SmartWatch](#)



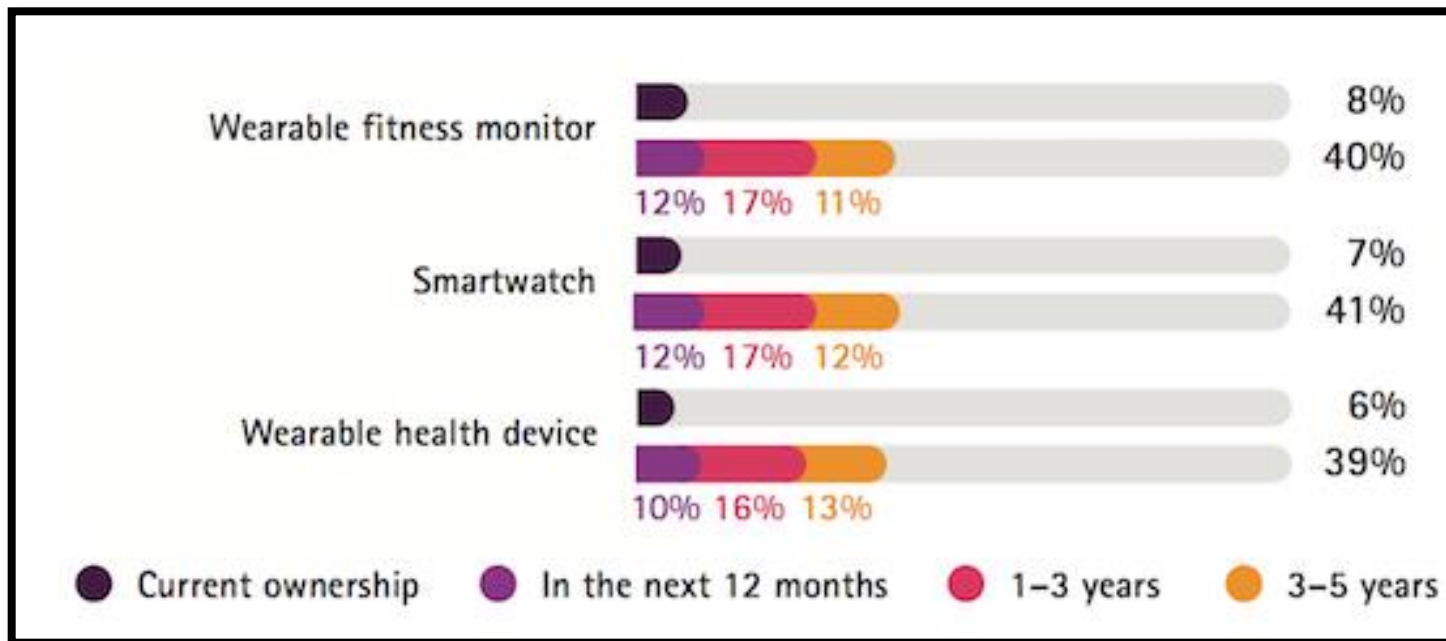
Casio [G-Shock](#)

Hmmmm!!!



Wearable Users

- Survey finds that an especially high % of consumers have challenges using wearable health devices
 - 24% said the products are too complicated to use
 - 22% said they did not set up properly
 - 21% said they don't work as advertised

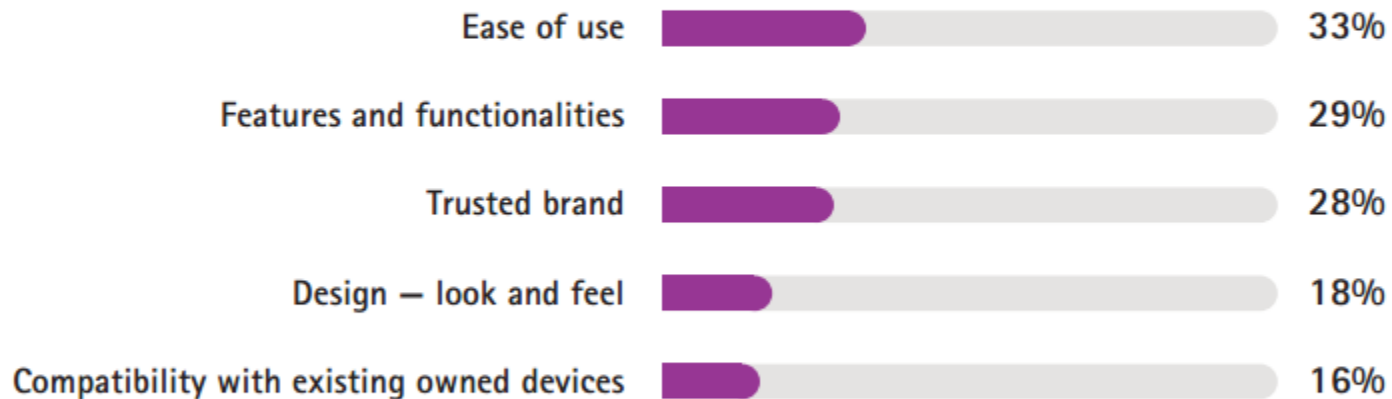


How do they select?

- Reliability is not on the list
 - “Trusted brand” is as close as it gets to quality or reliability

FIGURE 4 | FACTORS IN PURCHASE DECISION FOR INTELLIGENT DEVICES

Which of the following factors have been or would be the most important when making your decision to purchase an intelligent device?



BASE DEFINITION: All respondents owning or planning to buy an in-vehicle entertainment system, a wearable health device, a wearable fitness monitor, a home surveillance system, a smart thermostat or a smartwatch in the next 12 months (n=9110)

Samsung



- Issues with GearFit
- Not compatible with many cell phones
- Failure to connect
- Poor apps
- Finding new apps very difficult
- Launched prematurely

Players



Source: IMS Research, World Market for Wearable Technology - 2012

Wearable Tech is Everywhere.....

3/18/2014

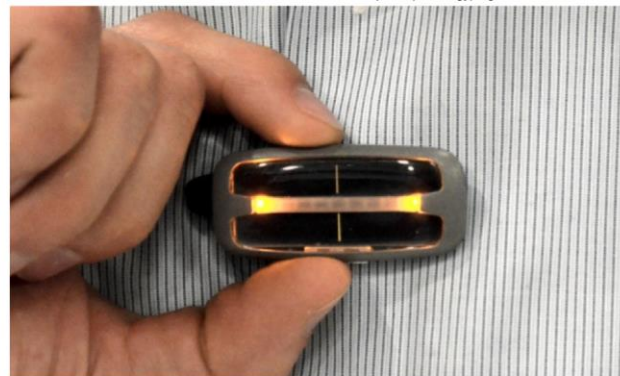
The best of London's Wearable Tech Show 2014 - in pictures | Technology | theguardian.com



SunFriend



AiQ smart clothing



SunSprite

Wrist Wallets

- The wallet is migrating to the phone
- Apple is leading this technology
- Security issues still abound
- Lots of new companies jumping in in 2015
- Batteries in belts and wristbands, sensors in shoes



New Applications

NeuroOn: World's First Sleep Mask for Polyphasic Sleep



FreeWavz: Smart Earphones With Built-In Fitness Monitoring



runScribe: Wearable for the Data-Driven Athlete



Carry Less, Adventure More: Survival Belt



New Applications



Beddit Sleep Monitor

January 5, 2015



Smart Sunglasses



Montblanc
TimeWalker Urban
Speed e-Strap add-
on to your current
watch

비즈니스 타워 12층 hakwon@ex1337.com

EXLEET *edge*

Family Oriented



Disney's MagicBand is a battery assisted **RFID** tag allows you to:

- Unlock the door of your Disney Resort Hotel room
- Enter theme and water parks (with valid admission).
- Check in at FastPass+ entrances.
- Connect Disney PhotoPass images to your account.
- Charge food and merchandise purchases to your Disney Resort hotel room (only available during your hotel stay).

No reliability data evident

How Wearables Intersect with the Cloud and the IoT, Joseph Wei, CPMT Wearables Workshop

Wearable GPS Tracker for Kids

TINITELL - Wristphone for kids

- 2G GSM SIM card for connectivity, to power the voice calls and GPS tracking
- Battery good for an hour's talk time on a single charge or seven days on standby
- It's also water resistant and sandbox proof, to ensure it's robust enough for outdoor child's play

Website states unit is water resistant.
No other reliability information



How Wearables Intersect with the Cloud and the IoT, Joseph Wei, CPMT Wearables Workshop

Wearing the Cure

- 29.1 million people in the US with diabetes
 - 350,000 using wearable insulin pumps
- Lux Research: clinical wearable devices should surpass their consumer counterparts in revenue by 2020



Beauty and Wearable Tech:
Miss Idaho Proudly Displays Her Insulin Pump



Medtronic's MiniMed Paradigm Revel Insulin pump senses blood sugar in real time

Will We Use Health Wearables?

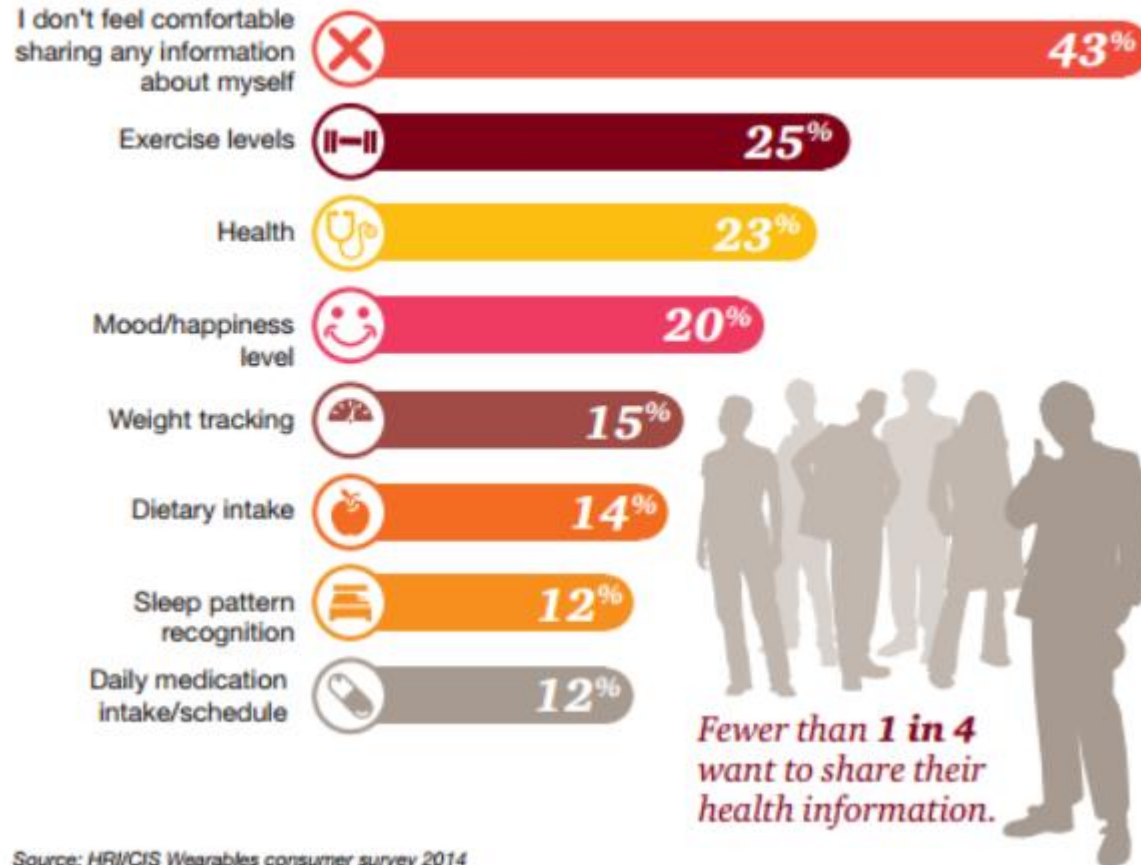


Source: HRI/CIS Wearables consumer survey 2014

- \$200 million went to wearable technology from investors for digital health
- 7.6 million devices shipped in just the US – a 200% increase over last year
- Linkage to insurance companies could lower costs but privacy and data protection issues need to be resolved
- However, consumers want low cost and many want their employer to cover the cost

Want to Share Your Health Data?

Figure 6: Many US consumers don't want to share health data with friends and family
Consumers were asked what kinds of information they would share with friends and family.

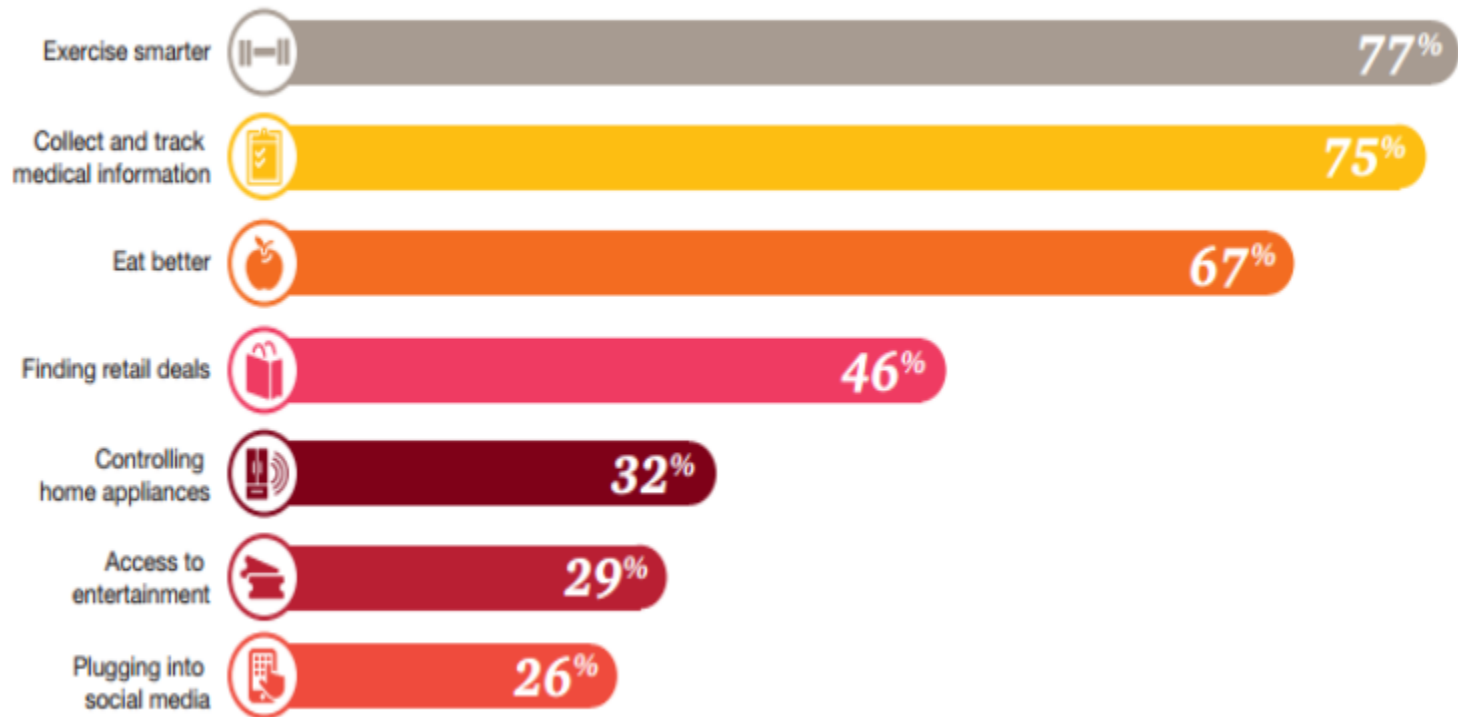


Source: HRI/CIS Wearables consumer survey 2014

What Do Consumers Want from Health Wearables

Figure 3: Health tops list of information US consumers want from wearables

Consumers were asked what information they want to receive from wearable technology.



Source: HRI/CIS Wearables consumer survey 2014

Why is Reliability a Challenge?

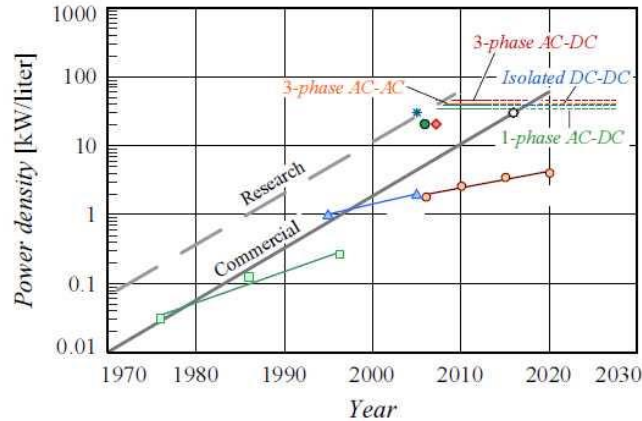


Figure 2. Power density trends of commercial and research systems and the Power Density Barriers.

Everything is Hot

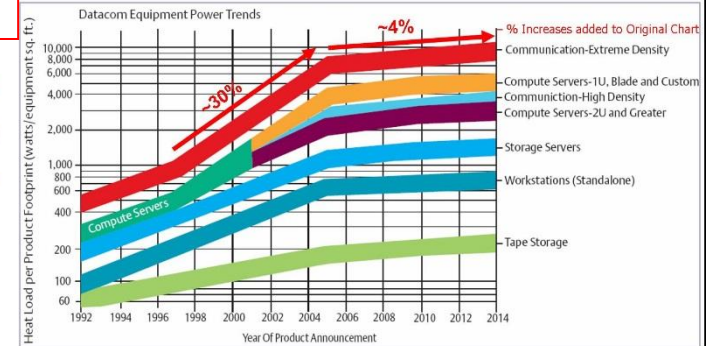
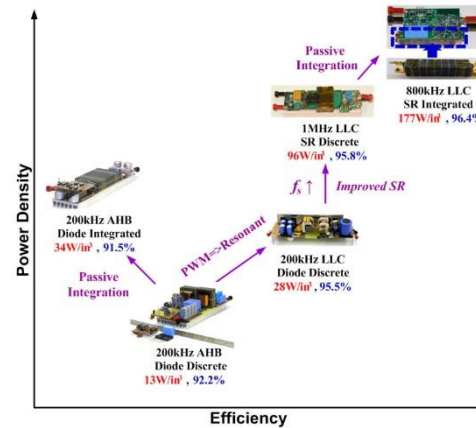


Figure 1. Equipment densities are rising even faster than once predicted.
© 2005 ASHRAE TC 9.9 Datacom Equipment Power Trends & Cooling Applications



Everything is Mobile



Everything is Everywhere

But “Reliability is Letting Wearable Tech Down”

- “Another month, another bad experience with regard to reliability of wearable tech – this time with the Fitbit Flex. When the silicon wristband was only about a month old, it started coming apart.....”
- “Did you try turning it off, and then on again? How about charging it?”
- “After the first time you go through that dance, you realize it will never ever work. The failure mode is 100% catastrophic from the point of view of the user.”

<http://wearabletechwatch.net/2013/09/06/reliability-is-letting-wearable-tech-down/>

<http://forums.jawbone.com/t5/SUGGESTIONS/Is-the-UP24-Reliable-now/td-p/79393>

How Have Wearable Consumer Electronics Failed?

- **Sweat**
 - Documented in blogs that Apple iPod Nano's have shorted out due to sweat
- **Strain relief**
 - Wearable on clothing, attached by a cord to power device, failed prematurely due to a lack of strain relief
- **Plasticizer**
 - First-generation of Amazon Kindle wiring insulation cracked/crumbled due to the use of non-optimized plasticizer formulation
- **Cyclic Fatigue**
 - Initial video game controllers experienced fatigue of solder joints on components attached to the backside of the push buttons

Terrible Wearables: Hall of Shame

- “In taking blood pressure readings, the Withings blood pressure monitor failed every time (but one), all at the same point”



<http://wearabletechwatch.net>



- Contacts rubbing skin raw
- Heat & sweat
- <http://www.n3rdabl3.co.uk/2014/07/lg-g-watch-charging-points-cause-injury-users/>

Terrible Wearables: Hall of Shame

- Fitbit Recalls Force Activity-Tracking Wristband Due to Risk of Skin Irritation
 - Complaints of itchy, irritated wrists
 - Allergic contact dermatitis
 - Either the nickel that's in the stainless steel part of the device
 - Or adhesives or other materials used in the strap



Terrible Wearables: Hall of Shame

- “Sunscreen melted my Nook”
 - A tiny warning on the can reads it can damage some fabrics materials or surfaces.
 - <http://bcove.me/hh5yfn26>

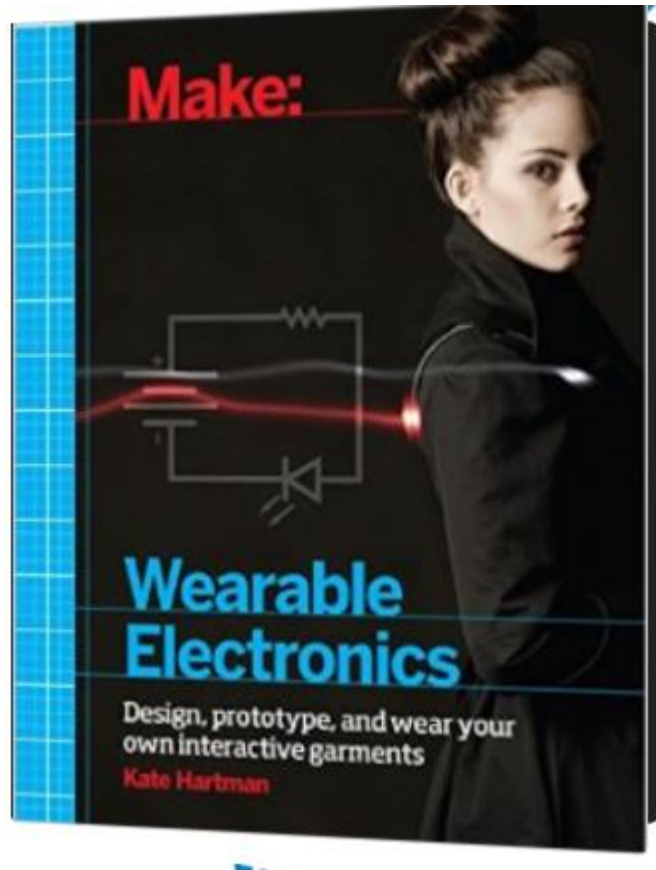


Pavlok: Is This a Wearable Device for You?

- Habit-forming wearable that will shock you! Literally.....
- Designed to shock the user when they do a pre-programmed bad habit
 - Wasting time online
 - Going to fast food restaurants?
 - Hitting snooze button on alarm clock
- Failure waiting to happen???



Uh Oh!!!!



- Pretty detailed approach to making your own wearable product.
 - Circuits
 - Components
 - Microcontrollers
 - Sensors
 - Actuators
 - Wireless
 - Conductive Materials
 - E-Textile Toolkits
- **However, reliability is not addressed**

What is Reliability?

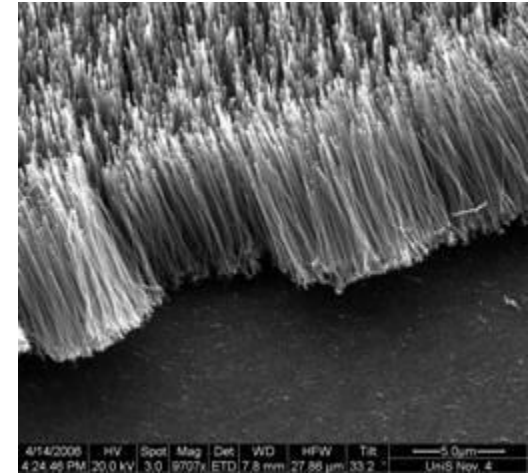
- Reliability is the measure of a product's ability to
 - ...perform the specified function
 - ...at the customer (with their use environment)
 - ...over the desired lifetime
- To ensure reliability, we have to think about
 - What is the product supposed to do?
 - Where is going to be used?
 - How long should it last?

What are Wearable Electronics?

- Wikipedia: “...miniature electronic devices that are worn by the bearer under, with or on top of clothing.”
 - That's It?!
- Alternative Definition
 - Technology attached to the human body or clothing that allows the wearer to monitor, engage with, and control devices, themselves, or their social network

Wearable Electronics Use Next Generation Technology

- What is 'Next Generation' Technology?
 - Materials or designs currently being used, but not widely adopted (especially among hi reliability manufacturers)
- Carbon nanotubes are not 'Next Generation'
 - Not used in electronic applications
- Ball grid array (BGA) is not 'Next Generation'
 - Widely adopted



Carbon Nanotube Array for
Tissue Regen. & Wound Repair

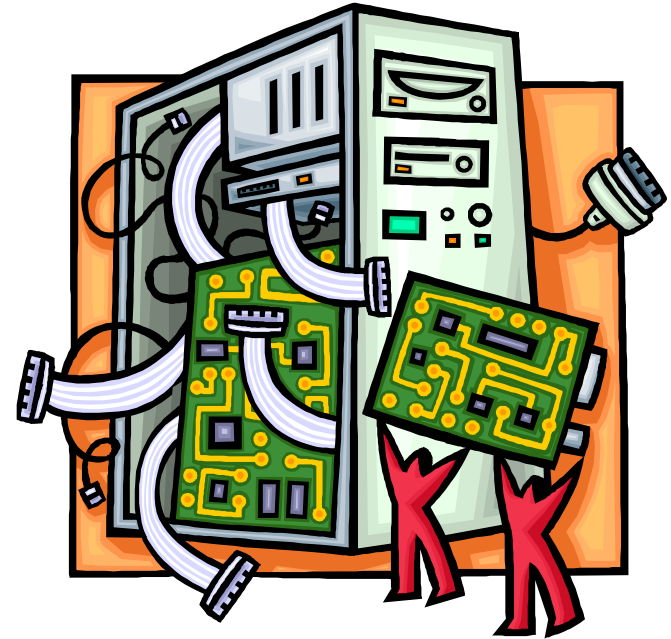
Next Generation Technology (cont.)

- Why is knowing about 'Next Generation' Technologies important?
- These are the technologies that you or your supply chain will use to improve your product
 - Cheaper, Faster, Stronger, 'Environmentally-Friendly', etc.
- However...



Reliability and Next Gen Technologies

- One of the most common drivers for failure is inappropriate adoption of new technologies
 - The path from consumer (high volume, short lifetime) to high reliability is not always clear
- Obtaining relevant information can be difficult
 - Information is often segmented
 - Focus on opportunity, not risks
- Sources are either marketing mush or confusing, scientific studies
 - Where is the practical advice?

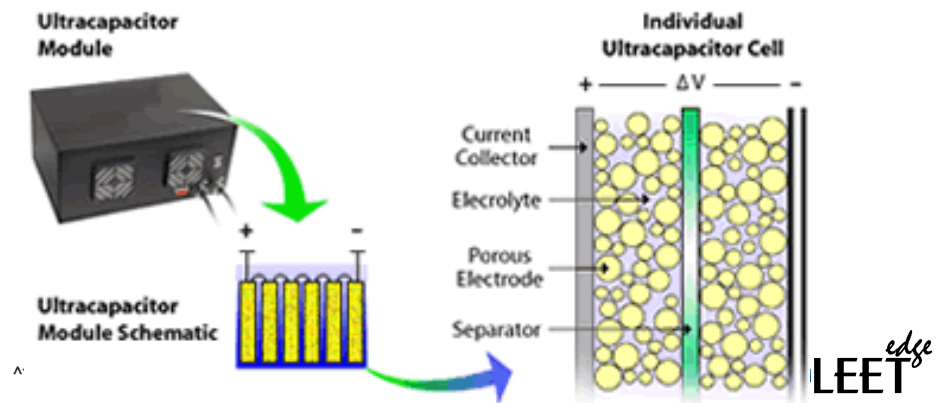


Next Gen Technologies: The Reality

- Market studies and mobile phone markets can skew reality of market adoption
 - Annual sales of >100 million may be due to one or two customers
- Mobile phone requirements may not match the needs of wearable electronics
- Market studies exclusively focused on volume
 - More relevant may be number of customers

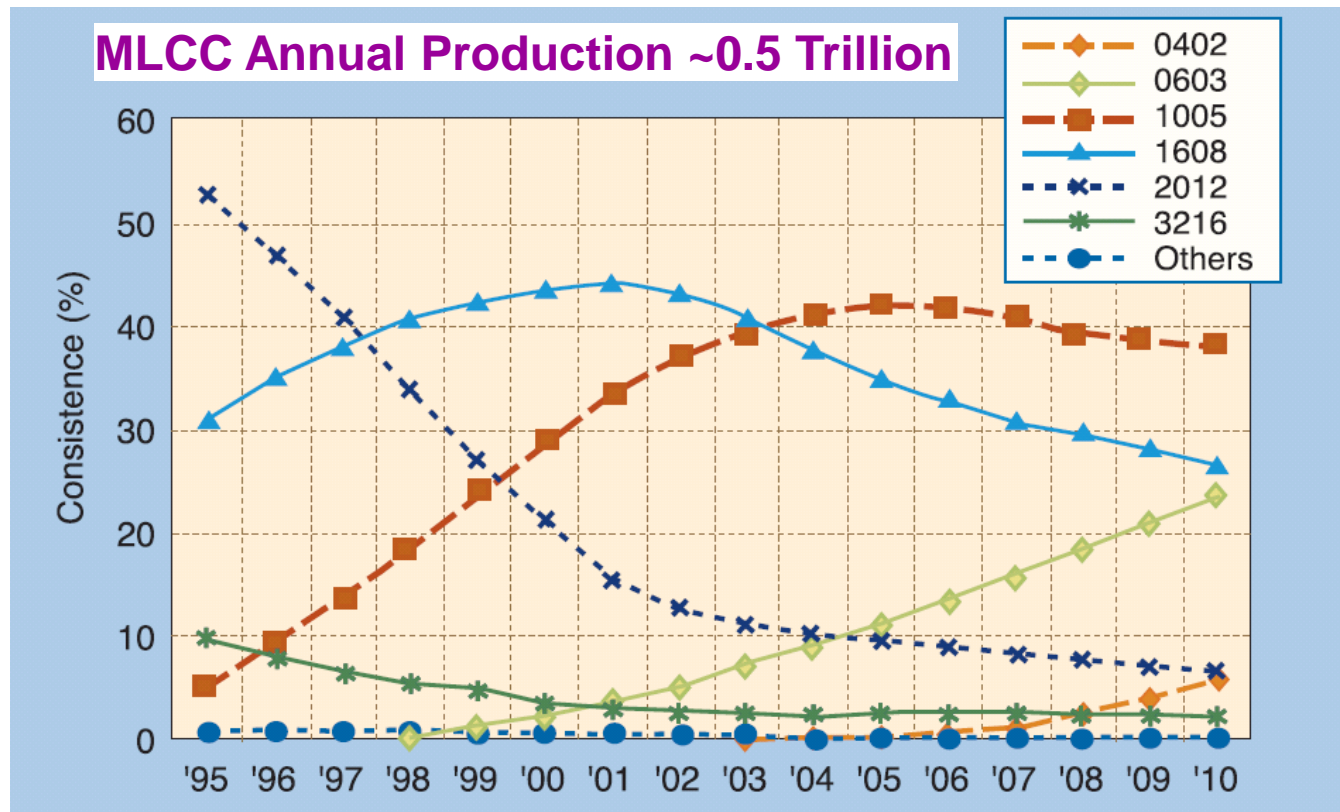
Examples of Next Gen Technologies in Wearables

- Embedded components
- Ultra-small components (i.e., 01005 capacitors)
- New substrate materials
 - Polyethersulfone, polyethylene terephthalate (PET), polyethylene naphthalate (PEN)
 - Polyimide is not a next gen technology
- Printed connections
 - Silver inks, copper inks, nanosolders, conductive polymers
- Organic displays
- Power Via Supercapacitors



“The Smaller the Better” - 0201 Ceramic Capacitors

Metric	English
0402	01005
0603	0201
1005	0402
1608	0603
2012	0805
3216	1206



- Based on volume, 0201 capacitors were 25% of the multilayer ceramic capacitor (MLCC) market in 2010

0201 Ceramic Capacitors: The Reality

- Actual high usage applications
 - Ultra small modules (primarily hearing aids) / high frequency
- Major users were limited to approximately 8 to 10 high volume companies in very benign environments and very limited lifetimes
- Attempts to integrate 0201 capacitor technology into more demanding applications, such as medical implants, resulted in quality issues, unexpected degradation, and major warranty returns

Why Care About Reliability? A Warning Lesson for Wearables

- “Durability”
- Case Study: Compact Fluorescent Lamps (CFLs)

Market Share has Dropped by >25%



CFL Market Profile: Data Trends and Market Insights, US Dept. of Energy, September 2010

CFL Reliability: Perception and Reality

- Prof. Siminovitch of UC – Davis has identified three (3) areas of dissatisfaction
 - Color quality
 - Dimming
 - Product longevity
- Numerous other websites / blogs have reported issues with CFL reliability
- Rensselaer Polytechnic Institute (RPI) found early failure rates of CFLs between 2 to 13 percent
 - Returns higher in thermally challenging environments (reflectors, high switching)
 - Indications that power supplies play a major role in failures

green.blogs.nytimes.com/2009/01/27/why-efficient-light-bulbs-fail-to-thrive/, Jan. 27, 2009, New York Times

Will LED Light Bulbs Best Your CFLs and Incandescents?, Popular Mechanics, August 4, 2010, <http://www.popularmechanics.com/science/environment/will-led-light-bulbs-best-cfls-and-incandescents>

Ensuring Wearable Electronics Reliability

- DfR at Concept / Block-Diagram Stage
 - Specification creation
- Part Selection
 - Derating and uprating
- Design for Manufacturability
 - Reliability is only as good as what you make
- Wearout Mechanisms and Physics of Failure
 - Predicting degradation in today's electronics

Bringing it All Together

- Two key specifications important to capture at concept/contract stage that influence reliability

Reliability expectations



Use environment

Reliability Goals

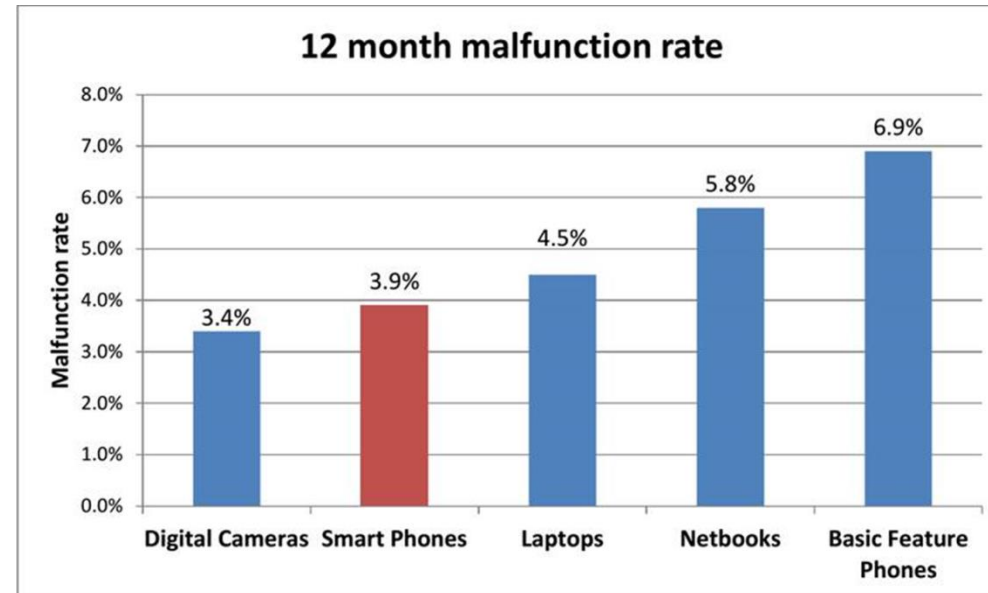
- Identify and document two metrics
 - Desired lifetime
 - Product performance
- Desired lifetime
 - **Defined as when the customer will be satisfied**
 - Should be actively used in development of part and product qualification
- Product performance
 - Returns during the warranty period
 - Survivability over lifetime at a set confidence level
 - MTBF or MTTF calculation should be primarily an administrative or marketing exercise (response to customer demands)

Desired Lifetime and Wearable Electronics

- What is the desired lifetime of wearable electronics?
- Rough equivalents: Clothes, shoes, watches, glasses, cell phones
 - Clothes: ??
 - Shoes: 3 months to 5 years (600 miles)
 - Watches: 3 to 20 years
 - Glasses: 2 to 5 years
 - Cell phones: 12 to 36 months
- With a new technology, there is an opportunity to influence expectations

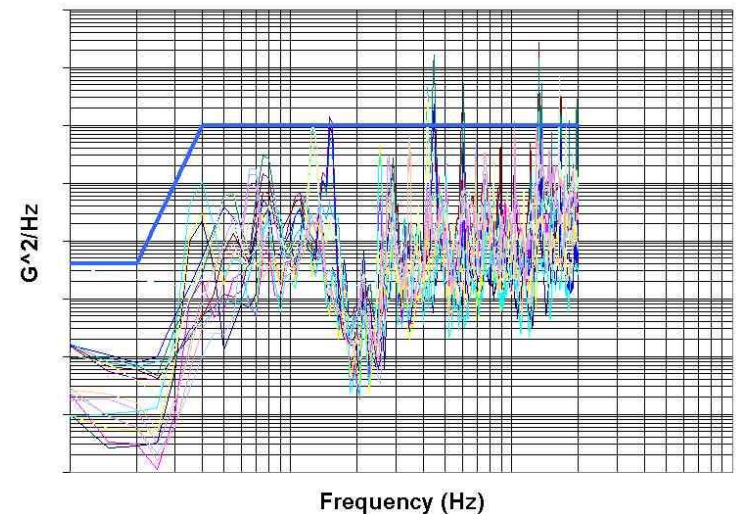
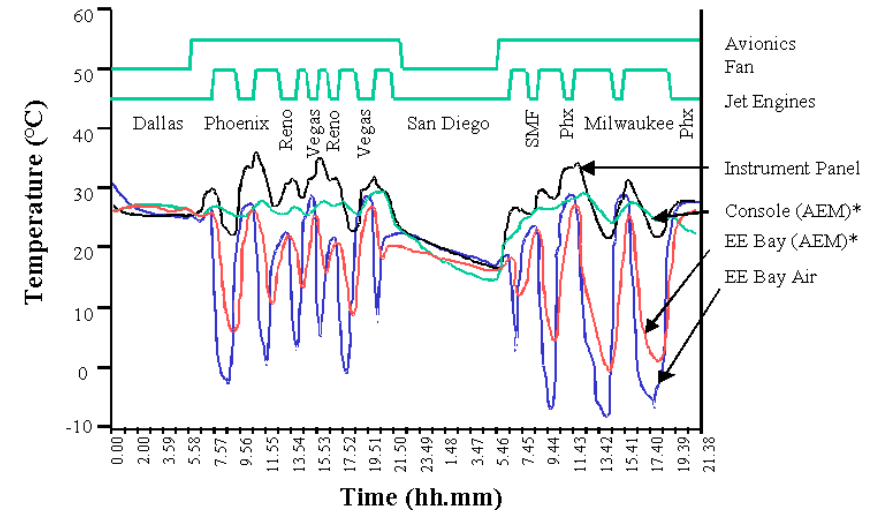
Product Performance: Warranty Returns

- **Consumer Electronics**
 - 5-25%
- **Low Volume, Non Hi-Reliability**
 - 1 to 2%
- **Industrial Controls**
 - 500 to 2000 ppm (1st Year)
- **Automotive**
 - 1 to 5% (Electrical, 1st Year)
 - Can also be reported as problems per 100 vehicles

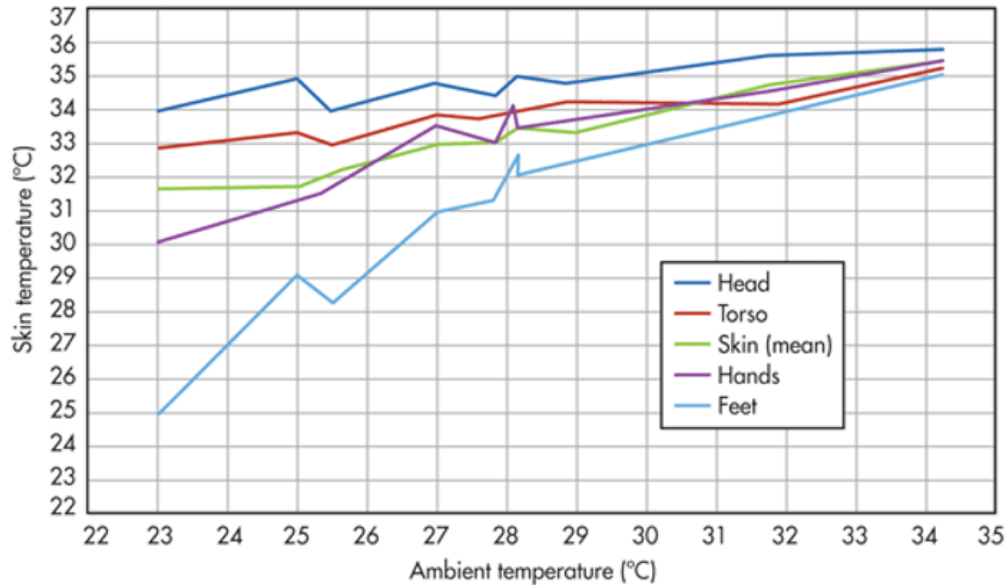


Identify and Quantify Failure Inducing Loads

- **Temperature Cycling**
 - Tmax, Tmin, dwell, ramp times
- **Sustained Temperature**
 - T and exposure time
- **Humidity**
 - Controlled, condensation
- **Corrosion**
 - Salt, corrosive gases (Cl₂, etc.), UV
- **Power cycling**
 - Duty cycles, power dissipation
- **Electrical Loads**
 - Voltage, current, current density
 - Static and transient
 - Electrical Noise
- **Mechanical Bending (Static and Cyclic)**
 - Board-level strain
- **Random Vibration**
 - PSD, exposure time, kurtosis
- **Harmonic Vibration**
 - G and frequency
- **Mechanical shock**
 - G, wave form, # of events



Field Environment: Body & Outdoor Temperatures



- Maximum temperatures likely not a significant concern
- Typically far below ratings

- However, very cold temperatures (below -20C) could be a challenge
 - Especially in combination with a mechanical load

Temperature	Avg. U.S. CLIM Data	Avg. U.S. Weighted by Registration (Source: Confidential)	Phoenix (hrs/yr)	U.S. Worst Case (hrs/yr)
95F (35C)	0.375%	0.650%	11% (948)	13% (1,140)
105F (40.46C)	0.087%	0.050%	2.3% (198)	3.8% (331)
115F (46.11C)	0.008%	0.001%	0.02% (1.4)	0.1% (9)

Field Environment: Mechanical

○ Vibration

- Not typically affiliated with human body, but outliers can occur (especially with tools, transportation)
- Examples: Jackhammer, reciprocating saw
- Have induced failures in rigid medical devices

○ Mechanical Shock

- Drop loads can reach 1500g for mobile phone (some OEMs evaluate up to 10,000g)
- Likely to be lower for lighter wearables, but could be repeated (i.e., affiliated with shoes)

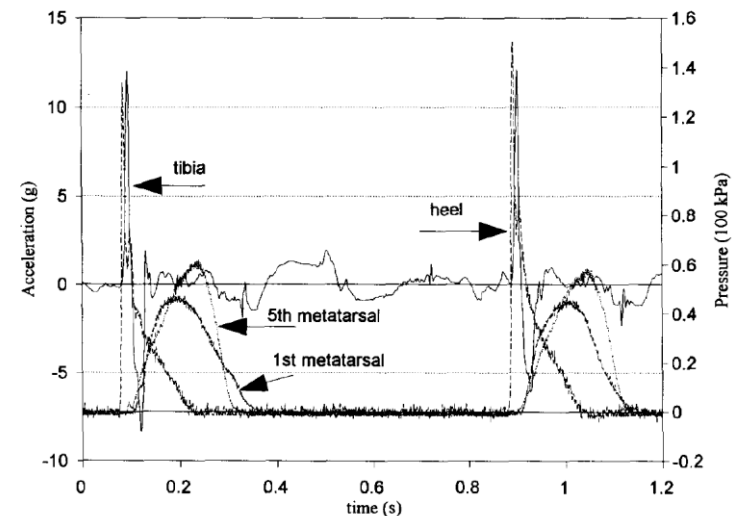


Fig. 7. Typical acceleration and pressure patterns recorded while subject was running.

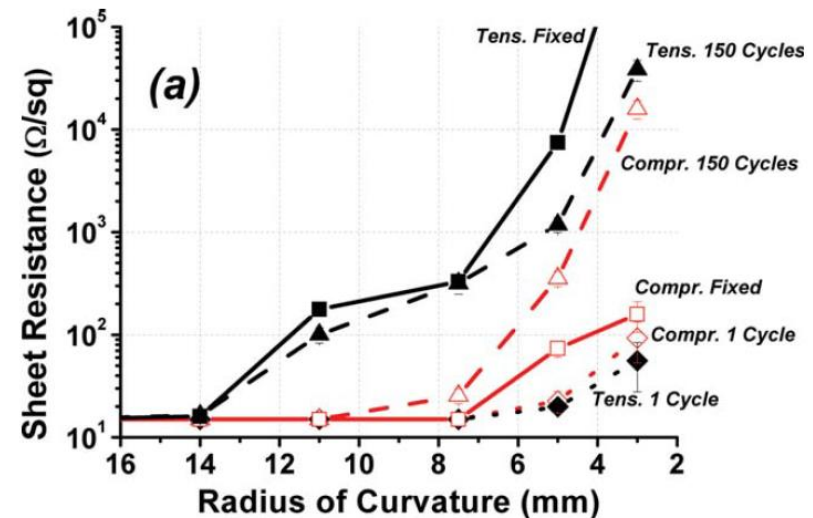
Field Environment: Mechanical (cont.)

- Bending (Cyclic / Overstress)

- Often considered one of the biggest risks in regards to wearables
- Certain human movements that induce bending (flexing of the knee) can occur over 1,000/day

- Case Study

- Some next-gen substrate materials experience a change in electrical properties after exposure to bending
- Aggravated by elevated temperature

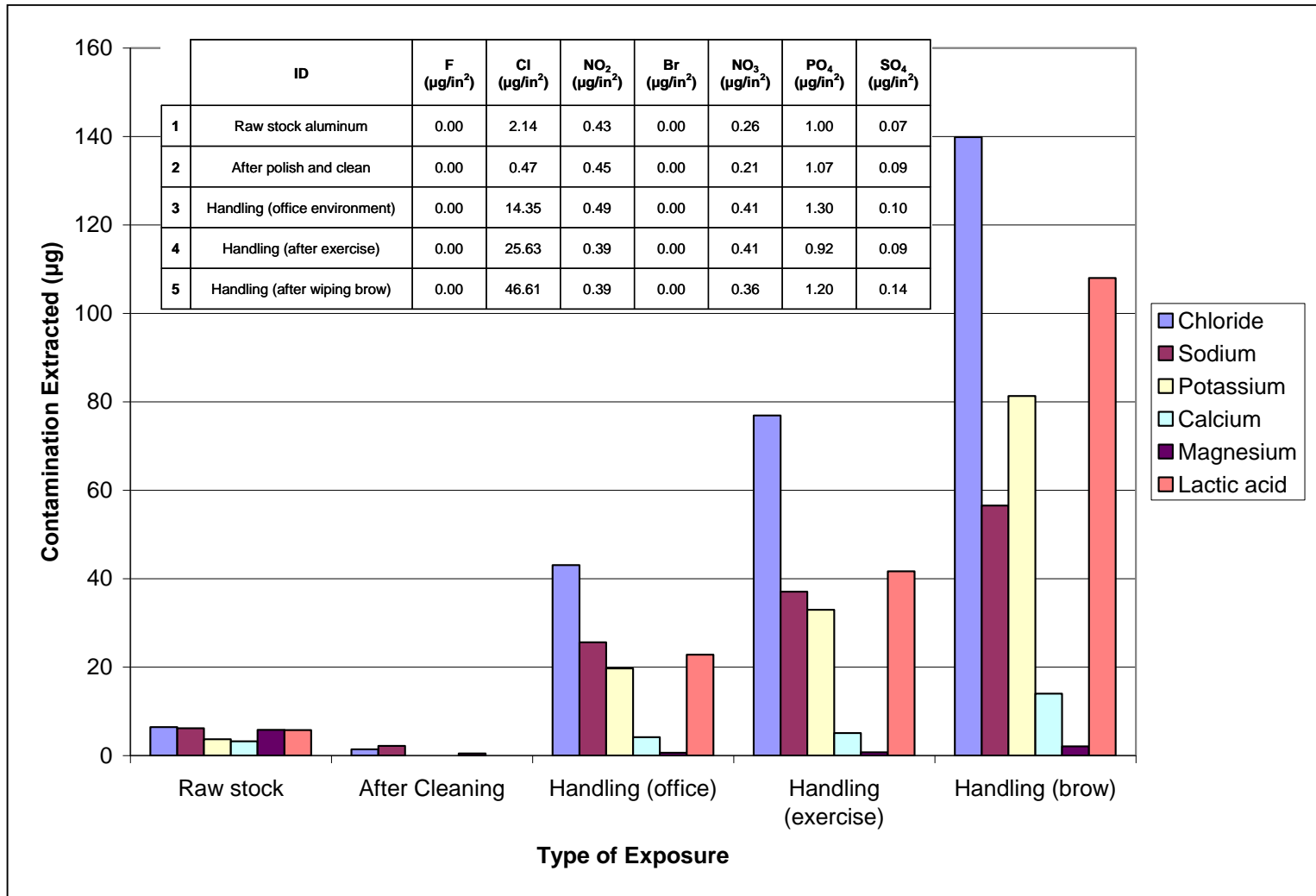


Corrosion: Handling / Sweat

- Composition of dissolved salts in water
 - Can include other biological molecules
- Main constituents after the solvent (water)
 - Chloride, sodium, potassium, calcium, magnesium, lactate, and urea
- Chloride and sodium dominate
 - Iron, copper, urocanate, and other metals, proteins, and enzymes are also present
- Main concern regarding sweat is as a source of **chloride**



Handling / Sweat (cont.)



Rain & Water Immersion Challenges

- Water & rain must be addressed for wearable electronics to survive
- Some cell phone manufacturers coat the product with either a conformal coating or a superhydrophobic coating to protect the electronics



Corrosion: UV Exposure



- Ultraviolet (UV) exposure typically not sufficient to induce degradation in electronic materials
- However, combination of temperature, moisture, and UV can break polymeric chains
 - Exact combination, and specific portion of the UV spectrum, is not always well characterized
- Stress corrosion cracking has been caused by sunscreens

UV Exposure

Annual UV Intensity – Global Picture

Enjoying the Sun Safely



Dangers of UV radiation exposure

- Short-term:**
- Sun burn
 - Suppression of the immune system
 - Eye inflammation (including photokeratitis, photoconjunctivitis)
- Long-term:**
- Skin cancer
 - Skin ageing
 - Cataract

The sun's rays

Mean annual UV radiation level
2007
Banded according to Global Solar UV Index

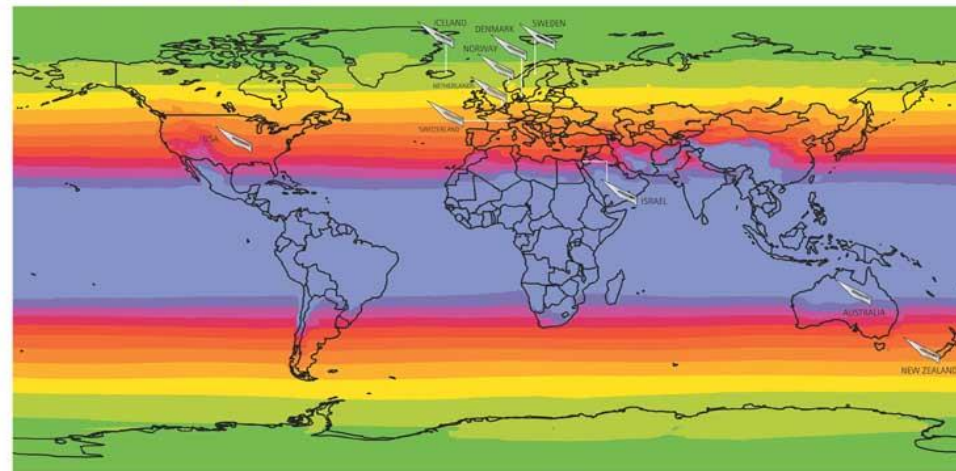


NO PROTECTION REQUIRED
You can safely stay outside!

PROTECTION REQUIRED
Seek shade during midday hours!
Slip on a shirt, slip on sunscreen and slap on a hat!

EXTRA PROTECTION
Avoid being outside during midday hours!
Make sure you seek shade!
Shirt, sunscreen and hat are a must!

The index describes the level of solar UV radiation at around midday, from zero (no UV radiation) upwards. The higher the value the greater the damage to skin and eyes, and the more care needs to be taken in the sun. UV radiation varies according to the season.



Annual UV Energy Calculations by City

City	Latitude	Average Total Energy at 340nm (W*hr/m^2/nm)	Average Annual Total Radiant Dose at 340nm (kJ/m^2/nm)
Singapore	1	426	1532
Paris, France	48	499	1796
Sao Paulo, Brazil	22	553	1991
Tokyo, Japan	35	570	2053
Guatemala	14	648	2334
Miami, FL	25	661	2380
New York NY	40	661	2381
Barcelona, Spain	41	662	2382
Brasilia, Brazil	15	662	2383
Melbourne, Australia	37	708	2549
Buenos Aires, Argentina	34	727	2618
Baghdad, Iraq	33	732	2634
Minneapolis, MN	44	735	2647
Townsville, Australia	19	743	2673
Madrid, Spain	40	748	2694
LA, CA	34	767	2761
Phoenix, AZ	33	869	3129

<http://www.dr-bmattech.co.uk/uv%20map.html>

Of Cities listed, Phoenix has highest avg annual exposure. Note: Model is isolated to UV. Humidity is not included.

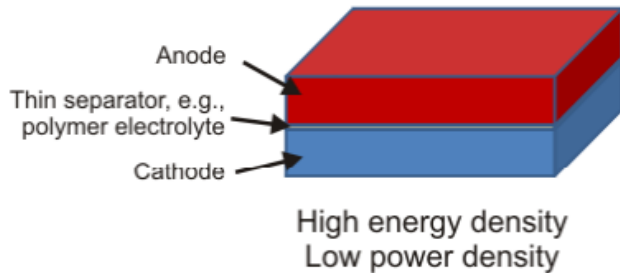
Other Challenging Environments for Wearables

- Washer / Dryer
- Cleaning fluids
- Mud / Dust / Water

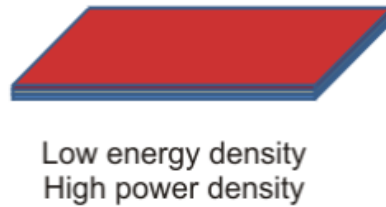


Battery Technology

THICK ELECTRODES

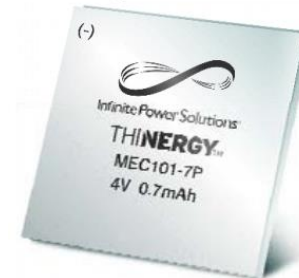
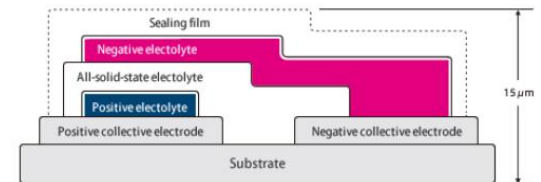
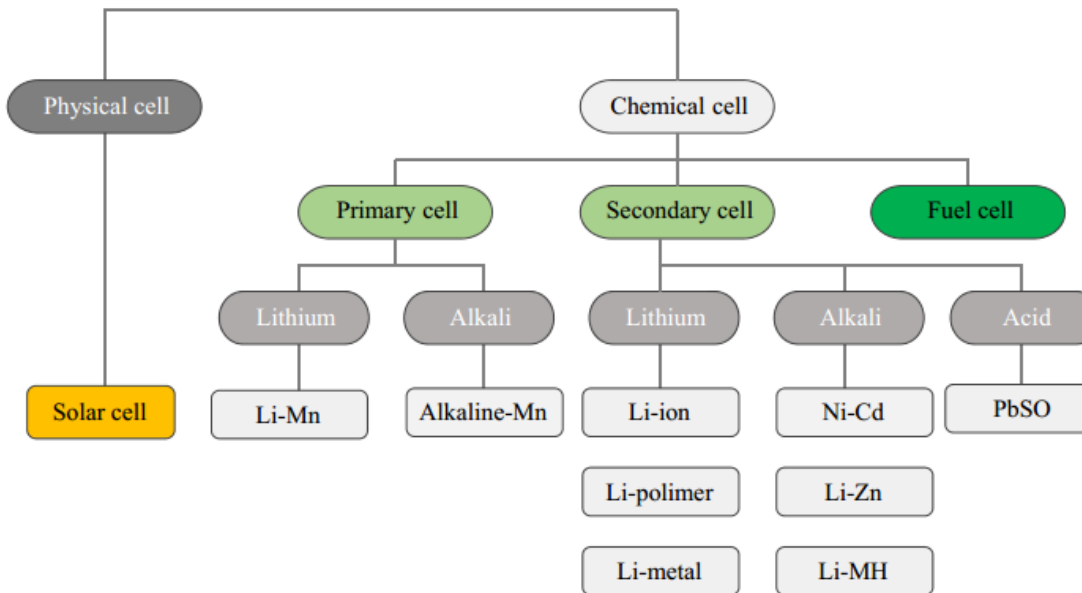


THIN ELECTRODES



- Batteries for wearables will implement different materials
- Will have either physical cell or chemical cell configurations
- Will take on multiple form factors
 - Cylindrical
 - Pouch
 - Prismatic
 - Thin Film

Battery category types



“Wearable Energy Sources,” Materials and System Inc, IEEE Wearable Technology Seminar

Flexible Chips

Flexible Chips

FleX™ Properties & Benefits

Flexible thin
high
performance
chips

Processors,
wireless
communication

Flexibility.

For integration into flexible systems or conformal on mounting of non-flat surfaces.

Durability.

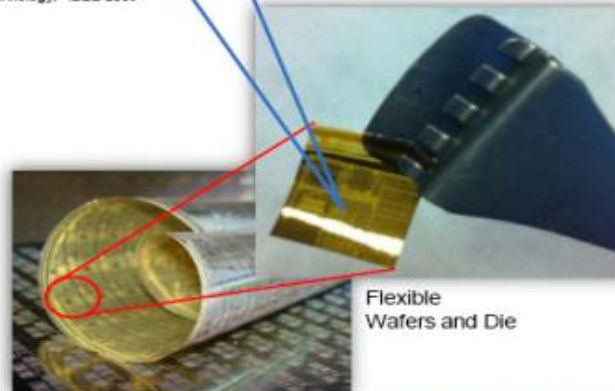
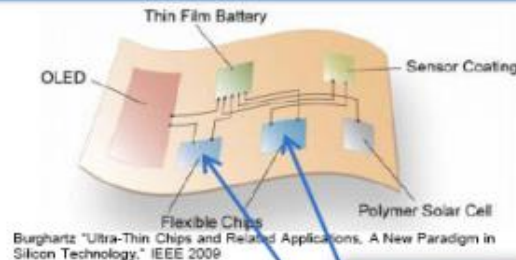
No silicon substrate improves tolerance to both mechanical and thermal shock.

Size.

Ultra thin form factor is useful in multi-chip packages and 3DIC.

Performance.

Transistors run 50%-100% faster on FleX wafers than on full thickness wafers.



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Environment (Best Practice)

- Use standards when...
 - Certain aspects of your environment are common
 - No access to use environment
- Measure when...
 - Certain aspects of your environment are unique
 - Strong relationship with customer
- Do not mistake test specifications for the actual use environment
 - Common mistake with mechanical loads

DfR's Wearables Center of Excellence

- DfR can assist you with the design and development of wearable electronics with:
 - Proper test plan development-selection of appropriate test methods to assess reliability
 - Material selection and compatibility
 - Testing to ascertain reliability
 - Drop Shock
 - Exposure to sweat
 - UV exposure
 - Sherlock ADA assessment
 - Root cause failure analysis to obviate issues

Conclusions

- Wearable electronics are an exciting revolution in our engagement with ourselves and the world around us
- However, there are clear risks
 - Wearables use new technology that hasn't been fully characterized
 - They'll be placed in environments not fully considered by the designers
- Results if wearable manufacturers don't use industry best practices & physics of failure to qualify their technology:
 - Unexpected failures
 - Delays in product launch
 - Advisory notices (medical tech)

Thanks!!

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