The Next Decade Capacitor Requirements from Automotive to Space Environments

CMSE, April 26th, Los Angeles, California, USA

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www.passive-components.eu

Content Focus

- Introduction
- Electronic Industry – Key Growth Area

  What Drives Capacitor Demand and Technology Selection ?

- Materials
  - Critical Supply Chain Management
  - New Materials – Next Gen Capacitors
  - Reliability, Sustainability and Life Cycle Assessment

- Summary

Introduction – EPCI

PASSIVE BLOG COMPONENTS

AWARDED TOP 40 ELECTRONIC PRODUCTS & COMPONENTS BLOG

ELEKTRA 2016 FINALIST

EPCI European Passive Components Institute

be active with passives !

Passive Components Global Daily News
collection of worldwide passive component news sortable by components and applications
weekly and monthly newsletters

WHO is WHO in Passives
free online database of global passive components manufacturers & suppliers

- **One of few educational and information resources dedicated solely to passive components**
- Established 2015, Elektra 2016 Finalist
- EPCI among the top 15 best rated global component blogs since 2018
- **PCNS Passives Symposium** organizer since 2017

EPCI Members and Supporters:

KEMET a YAGEO company · KYOCERA AVX · muRata INNOVATOR IN ELECTRONICS · WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

CAPXON · GLOBAL ADVANCED METALS · Itelcond · Jianghai · MGT

Panasonic INDUSTRY · speefox · SRT MICROCÉRAMIQUE · VISHAY The DNA of tech

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www.passive-components.eu

| Passive Components Educational & Information Blog

2023 passive-components.eu web profile:

Active visitors: ~**40K/month**
Google Search views: ~ **2 million views /month**
Google Search clicks: ~ **35 thousands clicks / month**
Newsletter: > **781** subscribers related to passive components
Top countries: USA, India, Germany, UK, Canada, France, Sweden


Europe 30%


Americas 27%


Asia 35%

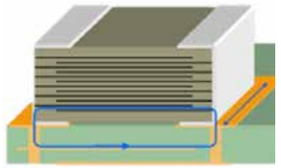
Key Growth Areas

IC Development Background

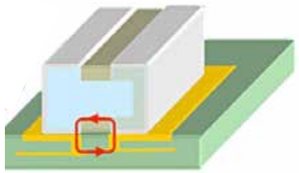
Semiconductor IC Development – Processors

DIE SCALING HAS DROPPED IC SUPPLY VOLTAGE

- ***Capacitors job decoupling more critical***
- ***Clock & data speeds making Di/Dt drawn larger***

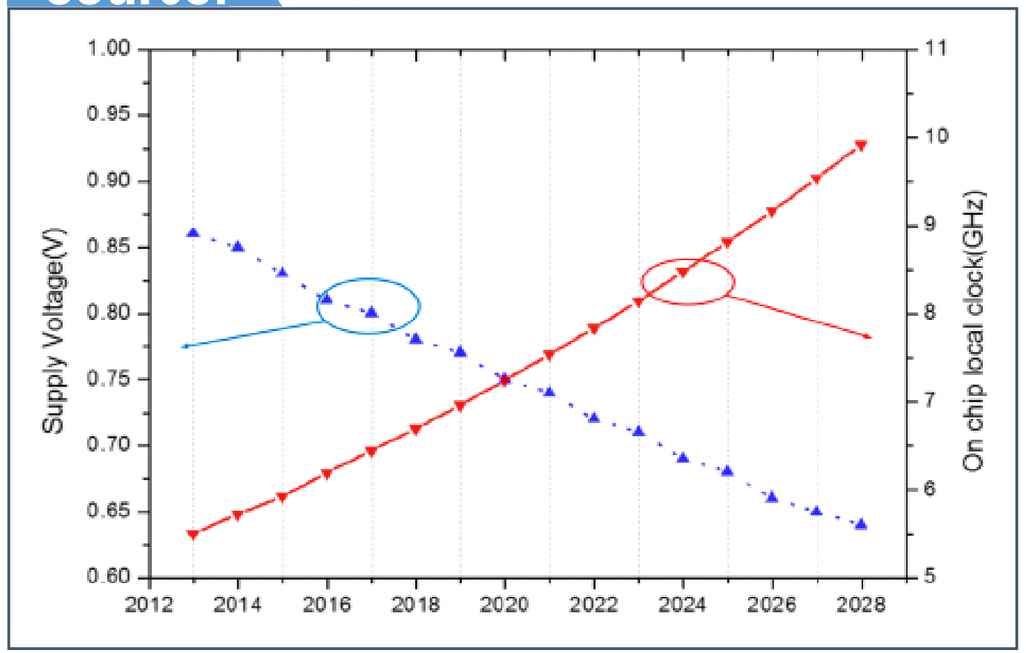


0805 MLCC
ESL ~ 600pH



0508 MLCC
ESL ~ 45pH

Source: ITRS



Best Fit Mass Volume Capacitor Technology:

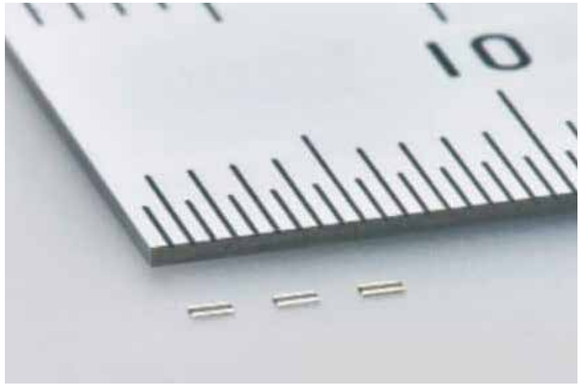
Past: Tantalum + MLCC

Current: MLCC Ceramic Capacitors

Future: Integrated on Chip

Capacitor Requirements

- Low ESL
- Low ESR
- High power
- Small Size
- Low Profile



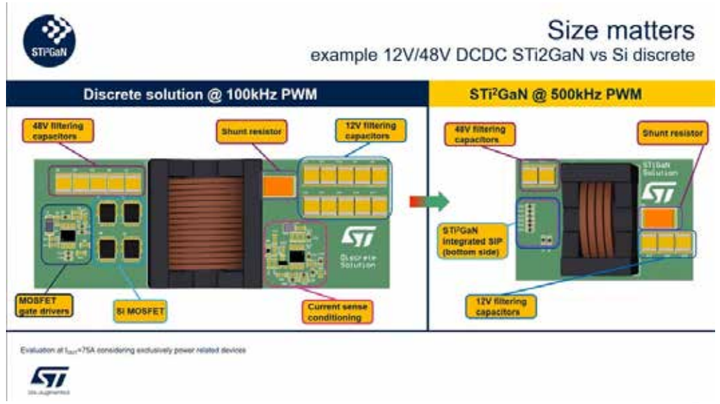
source: Tayo Yuden

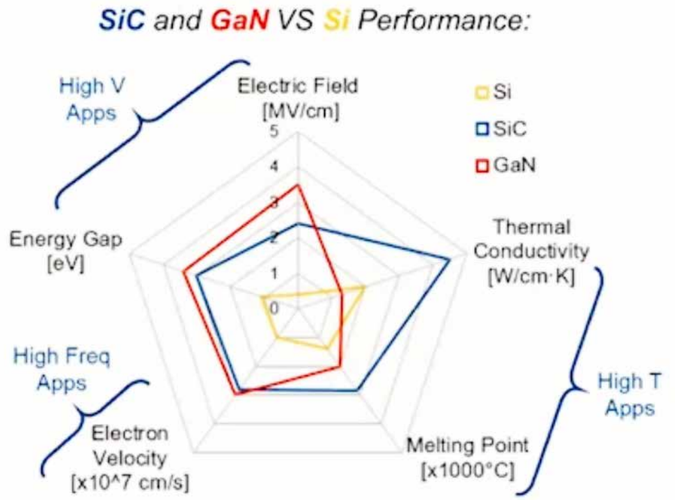
Reverse geometry
MLCC 0.47uF 4V size:
0.52 x 1.0 x 0.1 mm

IC Development Background

High Power Handling & Efficiency

Semiconductor IC Development – Wide Gap GaN/SiC Transistor „Revolution“





48 V three-stage synchronous buck converter with GaN technology

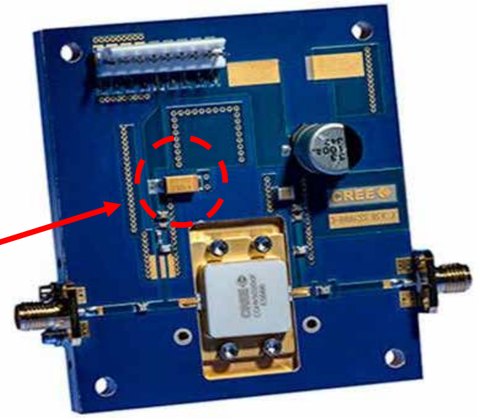
Need for Low Loss, High Power Components

Output Capacitor Changes:

- Lower ESR, High Ripple Current
- Low ESL, Higher Frequency
- Lower Capacitance Needed
- Small & Thin Profile
- **Move away from tantalum & electrolytics to MLCC Class II or Class I** output capacitors

New Requirements:

- **Stable Gate Drive Voltage Capacitors** (tantalum)
- Output low loss, high power inductors



Key Growth Areas

Mobile Internet / 5G

5G Key Technology Advancements

Low Latency

High Downlink Speed

- Multiarray Antennas (MIMO) & Beamforming
- Higher Frequency

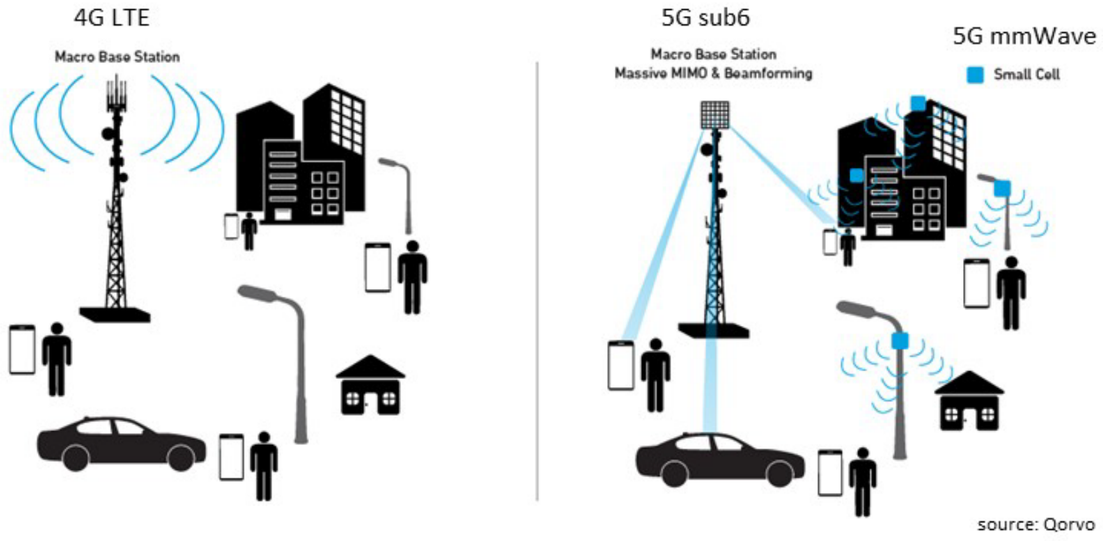
Low Interference

More Focused Energy & Energy Savings Potential

High Air Attenuation & Short Range

Increase Bandwidth & Device Coverage Density

Moisture & Barriers (walls) Attenuation

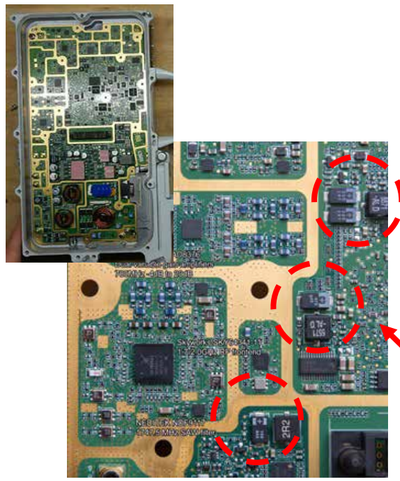


5G network will consist macro base station at 5G sub 6GHz (in combination with existing 4G) covering larger areas and 5G mmWave micro base stations and small cells to provide high speed hot spots

! 5G Calls for New Infrastructure Architecture !

to use its potential

Parameter	4G	5G	
	4G LTE	5G (Sub-6G)	5G (mmWave)
Frequency	2.1GHz	2-6 GHz	6-60GHz
Downlink Speed	1.2 Gbps	6.5 Gbps	18 Gbps
Latency	10-30ms	5-6ms	< 1 ms
Average Range (from a tower)	10km	1-6km	300m
Device Coverage Density	1 million devices per $500km^2$	1 million devices per $100km^2$	1 million devices per $1km^2$
Implementation	Macro Base Stations	Macro Base Stations	Micro Base Stations & Small Cells



Harsh Environment
Reliability
Low Profile

Small & Low Profile BS ~ 5G mmwave
At least **8x low profile D case** tantalum capacitors

Key Growth Areas

Automotive

Heterogenous Vehicle Connectivity

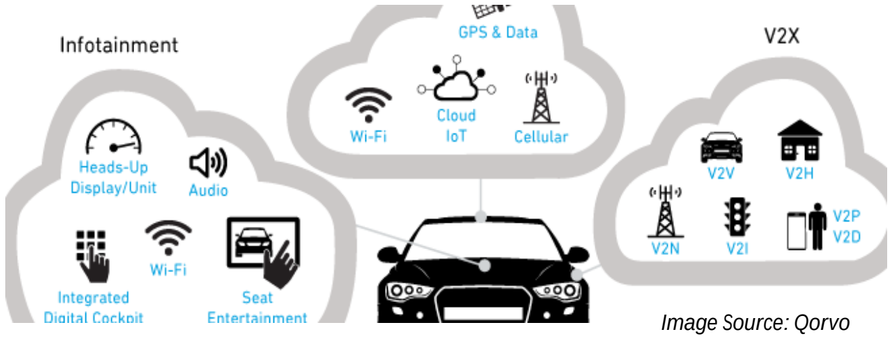
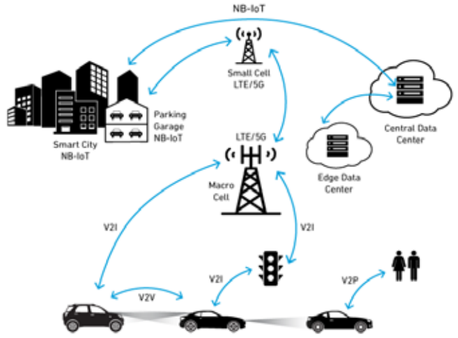
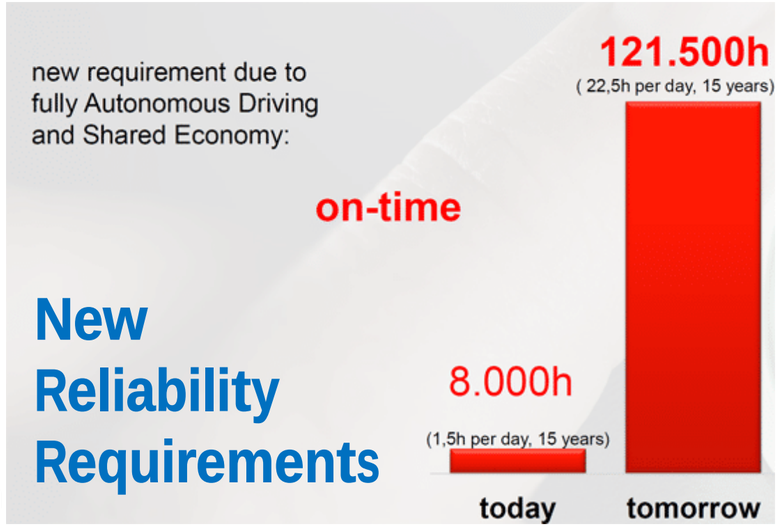


Image Source: Qorvo



V2X Communication

- Fast real time reaction required - can not rely on external network
- Too much latency is intolerable
- V2V may become the critical communication



The Amount of Data in an Autonomous Vehicle

> 4,000 GB Per Day

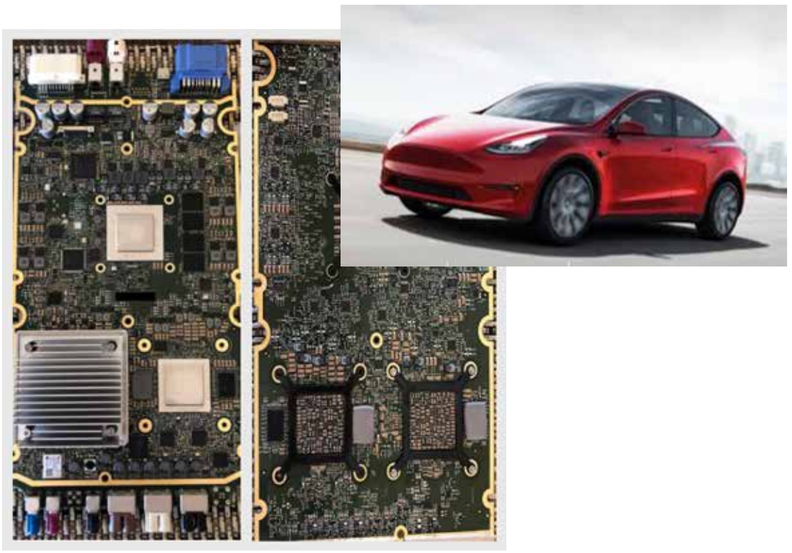
- Connected Car is becoming the prime IoT connected device with higher bit rate then smartphone

Interactive Cabine

- Focal Point of AI and human interface

Each Vehicle is becoming

- It is own cloud
- Large cloud data center
- **High power computing center**



Tesla Autopilot Computer Board Model 3,S,X

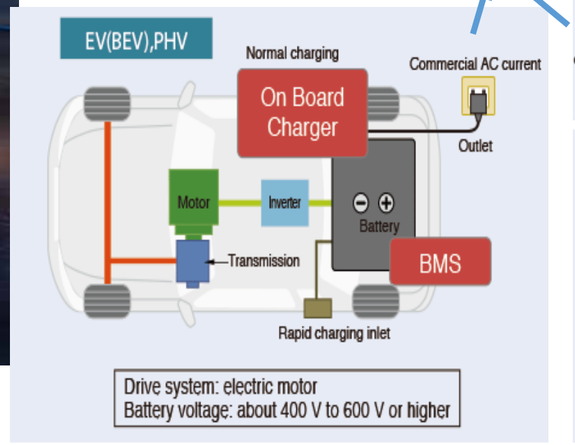
Key Growth Areas

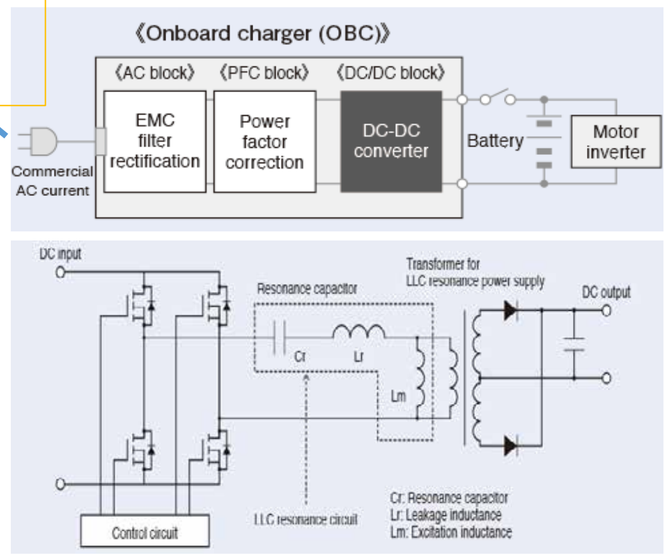
Automotive – EV/HEV

Lamborghini Sián
first supercapacitor-based hybrid V12

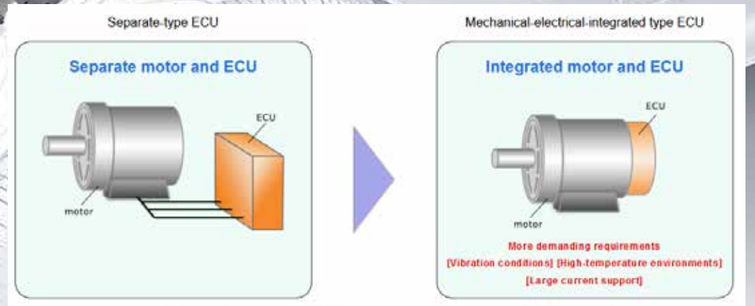
Lamborghini supercapacitors Terzo Millennio.
4 electric motors powered by supercapacitors as its energy storage devices located on body panels

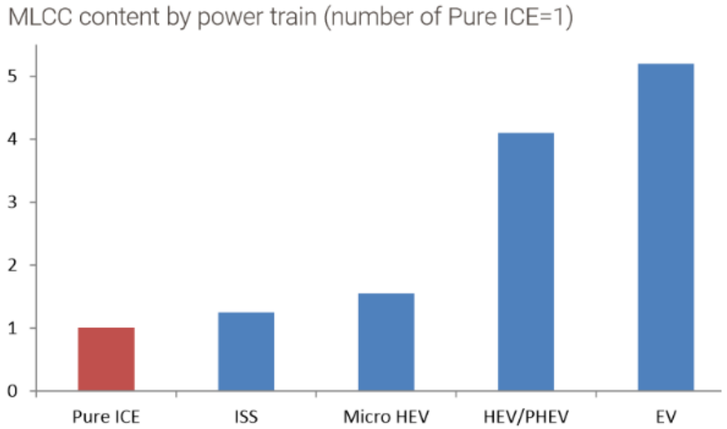
! EE Power Supply Infrastructure





EV/HEV Integrated Power
eMotor, Transmission, Electronics





- More Components
- Smaller & Higher Temperature
- Higher Voltage & Power
- Component Selection Changes
- New Applications
- New Technologies

Source: Bosch Mobility Solutions, TTI, TDK, Lamborghini, Panasonic

Key Growth Areas

Automotive – EV/HEV

High Power Switching & High Processing Power & Lowering of Processor Voltage

NOISE SUPPRESSION & EMC SHIELDING CHALLENGES

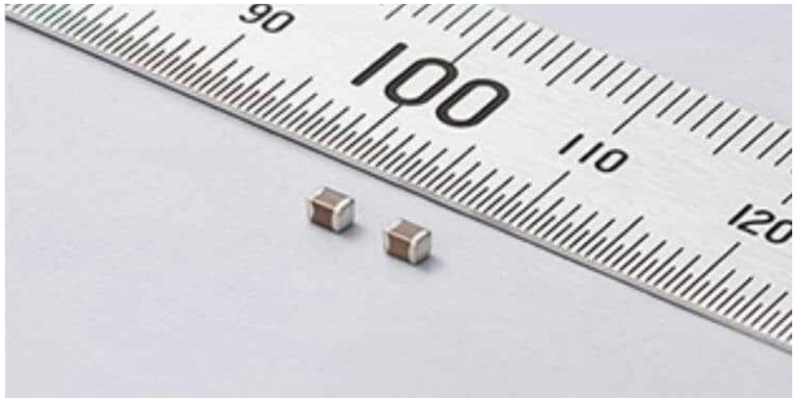
CAN-FD high speed, high accuracy miniature ceramic resonators

High Speed Data Transmition

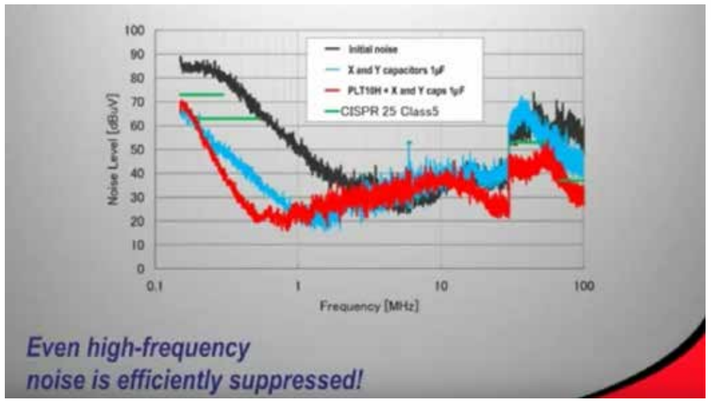
- **Integration & Miniaturization** of detection sensors (cameras, LIDAR, radar, etc…)
- **Power Over Coax** for image data transmission combines data and power transmission over a single coaxial line to reduce the amount of cable

Noise suppression by high current common (500mA) mode chokes in miniature 0201 case size

MLCC 10uF/25V in 2012 case size for 12V line smoothing applications in automobiles



Impact of safety capacitors and common mode choke to EMI suppression effectiveness



source: Murata; passive-components.eu

Key Growth Areas

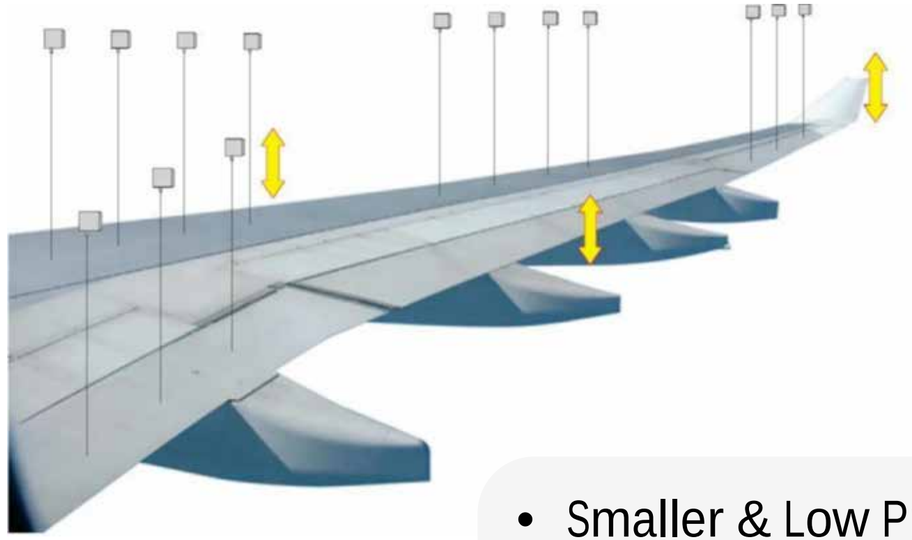
IoT

IoT / Industry 4.0 / Wireless will drive energy harvesting methods, circuits & modules in wide range of applications – aerospace, defence, consumer, medical, industrial …

Wearables / Medical / Defence

Miniature & Flexible designs

Wireless Sensors / Industrial IoT / Industry 4.0



IoT Will Drive Passive Components Volumes

Wireless connectivity with edge AI increases overall hardware content

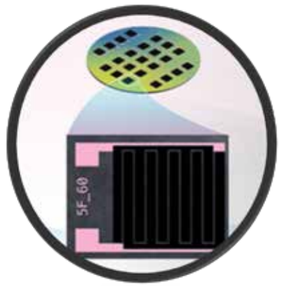
- Smaller & Low Profile Components
- 24/7/365 Operation
- High Reliability
- Lower Voltages

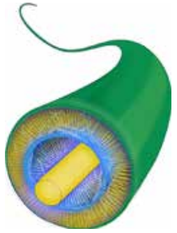
Key Growth Areas

Energy Storage – Power of the Future ?

Flexible Supercapacitors

CMOS-based Micro-Supercapacitors





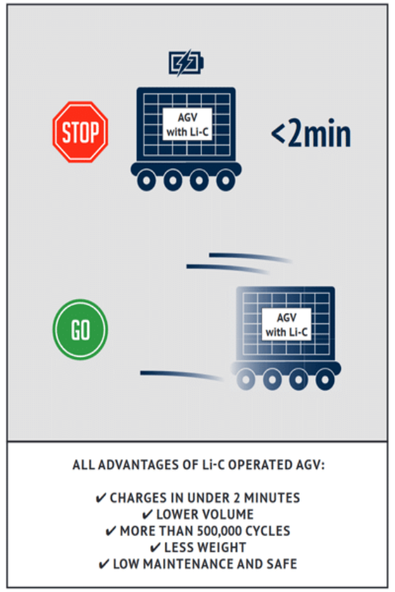
Cable Supercapacitors

Hybrid Energy Supercapacitor vs Battery in Transportation

	BATTERIE	ENERGY-C
CONSTRUCTION	2 x 12V 75 Ah in series	6 x 5000F in series
RATED VOLTAGE	24V	24V
EFFECTIVE STORAGE ENERGY	1.800Wh	40Wh
RANGE	6 ~ 8h	700 meters (ca. 12 min)
CHARGE TIME	ca. 4h	<2min
VOLUME	16l	5l
WEIGHT	53kg	4,4kg (in future 2kg)
NUMBER OF CYCLES	~1000 cycles	>500.000 cycles

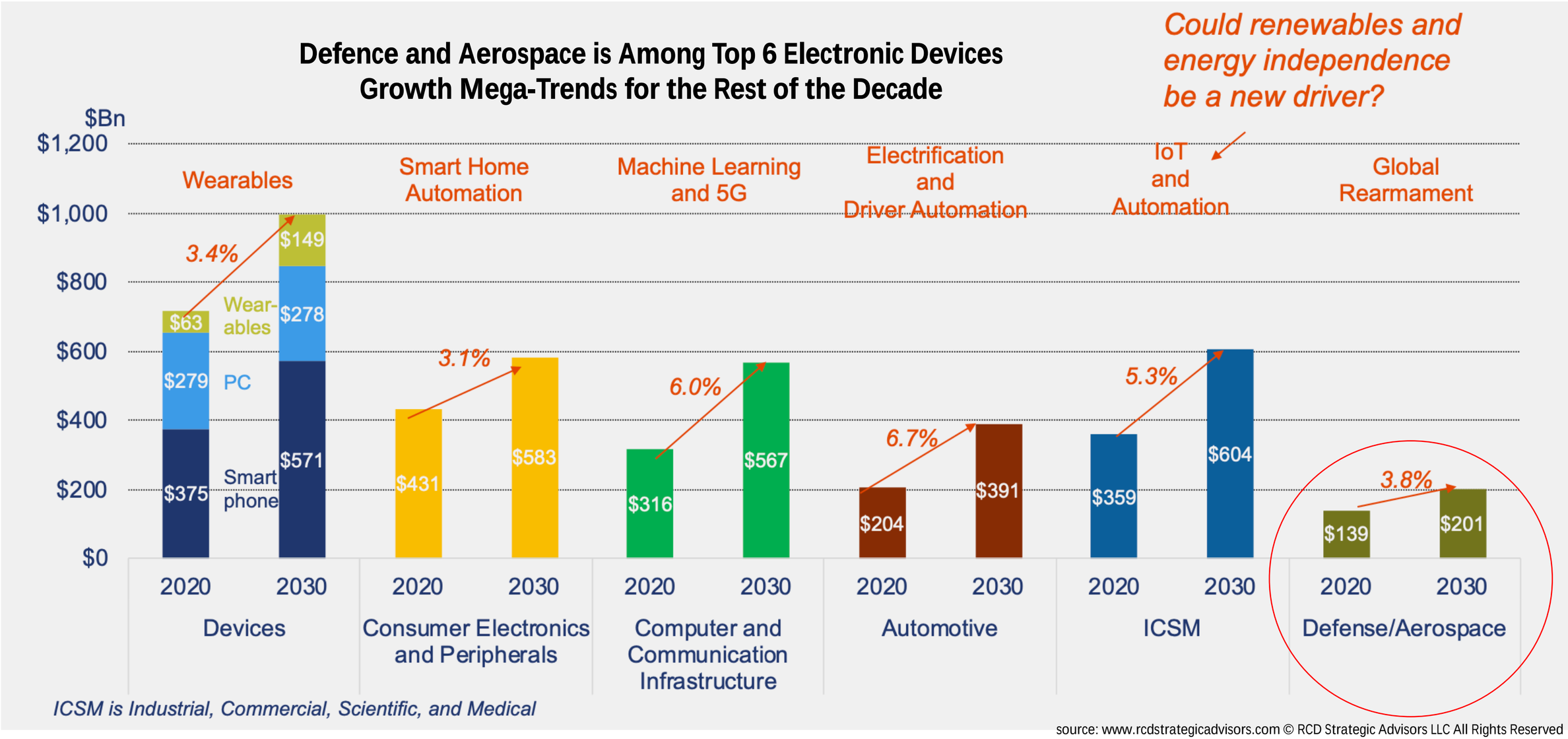
Driverless transport AGV Automated Guided Vehicles

Source: Jianghai-Europe



Key Growth Areas

Mega Trends for the Rest of the Decade



ICSM is Industrial, Commercial, Scientific, and Medical

MATERIALS

“The Next Decade on Passive Components will be about Reliability, Sustainability & Materials”

PCNS Passive Components Networking Symposium, September 2021, Milano, Italy
www.pcns.events www.passive-components.eu

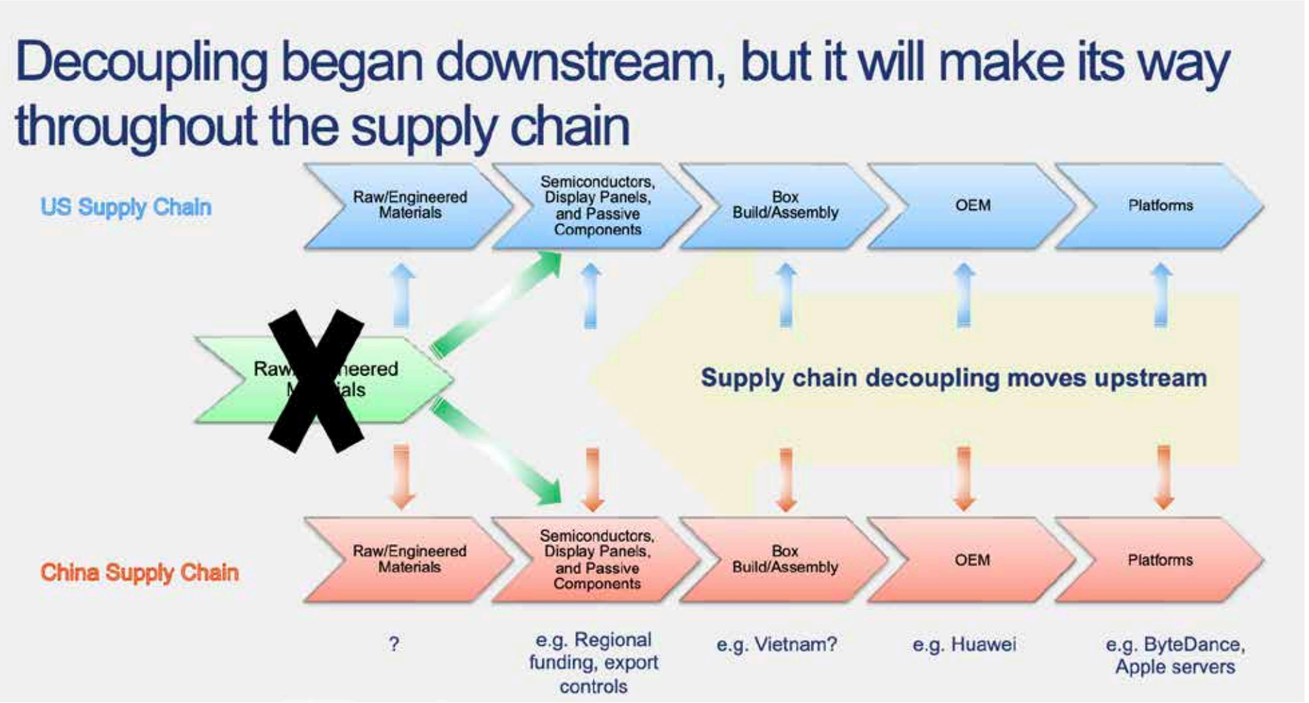
Supply Chain Management

The Era of Globalisation is Over

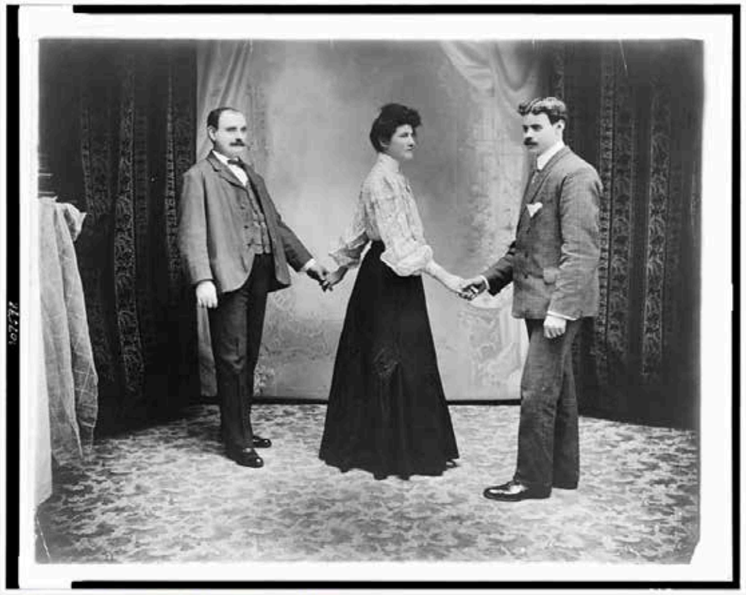
REUTERS

U.S. aims to hobble China's chip industry with sweeping new export rules

By Stephen Nellis, Karen Freifeld and Alexandra Alper
Oct. 10, 2022



How to Dance with Two Separate Partners



Source: D.A. Sigerist, fotographers, N.Y.C

Murata Duplicates Supply Chains to Manage Rapid U.S. – China Decoupling

19.10.2022 1

Murata Manufacturing president says to NIKKEI ASIA the U.S. and China economies are decoupling more quickly than...

Critical Material Supply Chain Management

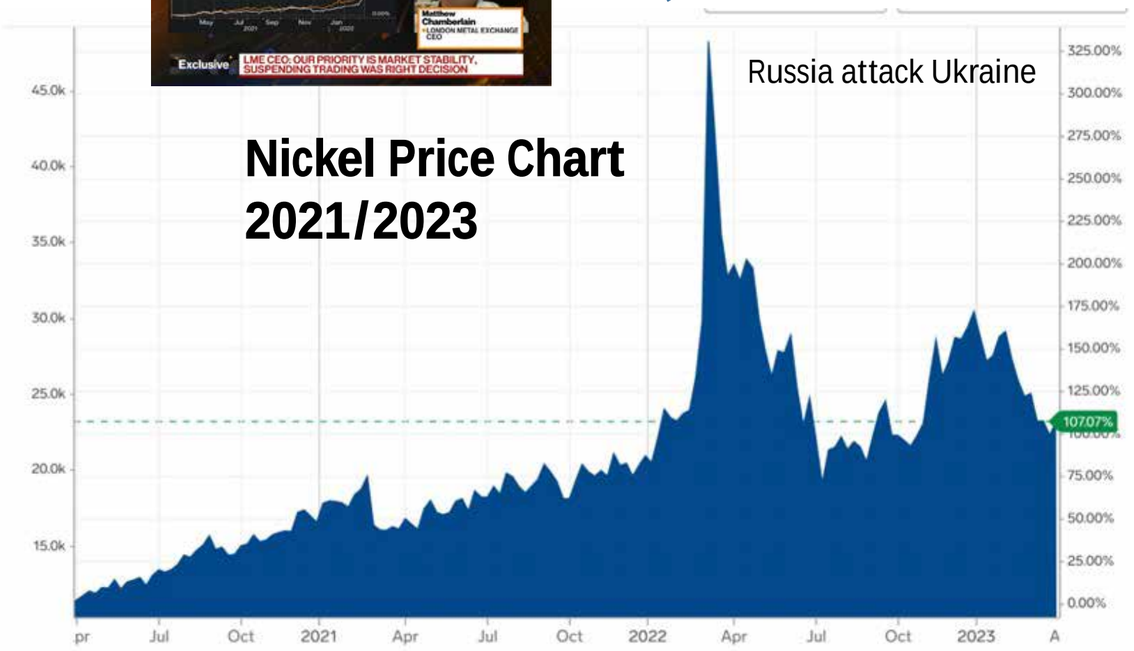
Key Capacitor Metals

Nickel

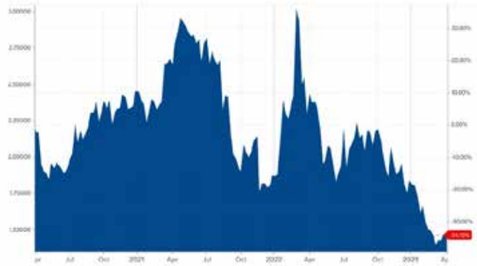
LME Halts Nickel Trading After Unprecedented 250% Spike

Material Supply Chain Evaluation and Managements Has to Become Critical Element of Component Designs

Nickel Price Chart 2021/2023



Palladium Price Chart 2021/2023



Russia supplies over 40% of the world's supply of palladium and 17% of the world's top-grade nickel.

The price of palladium, has risen over 50% since the invasion, but there are a number of South African suppliers like Impala Platinum, Northam Platinum, Sibanye-Stillwater and Anglo-American Platinum.

Nickel experienced unprecedented spike on March 8th, 2022 as the impact of Russia-Ukrain war and speculations. LME halted its trade for few days.

Sourcing Assurance is a New Value Driver

Electronic Components – Sustainability Requirements

17 United Nations´ Sustainable Development Goals

[The 2030 Agenda for Sustainable Development,](#) adopted by all United Nations Member States in 2015

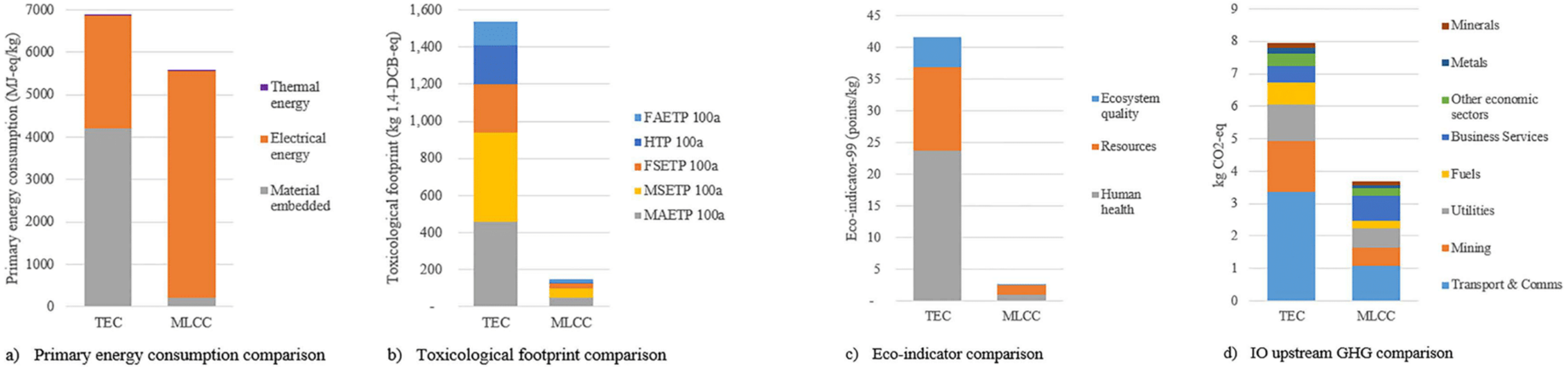
More information: https://sdgs.un.org/goals

Set of Regional Requirements & Standards

- RoHS
- WEEE
- REACH
- Conflict Minerals
- Environmental Management
- Life-Cycle Assessment
- ….

Example: Capacitors Life Assessment Case Study

Target: Tantalum Electrolytic Capacitors (TEC) vs MLCC Ceramic Capacitors Environmental Impact Comparison for Automotive Power Supply Design Consideration



a) Primary energy consumption comparison

b) Toxicological footprint comparison

c) Eco-indicator comparison

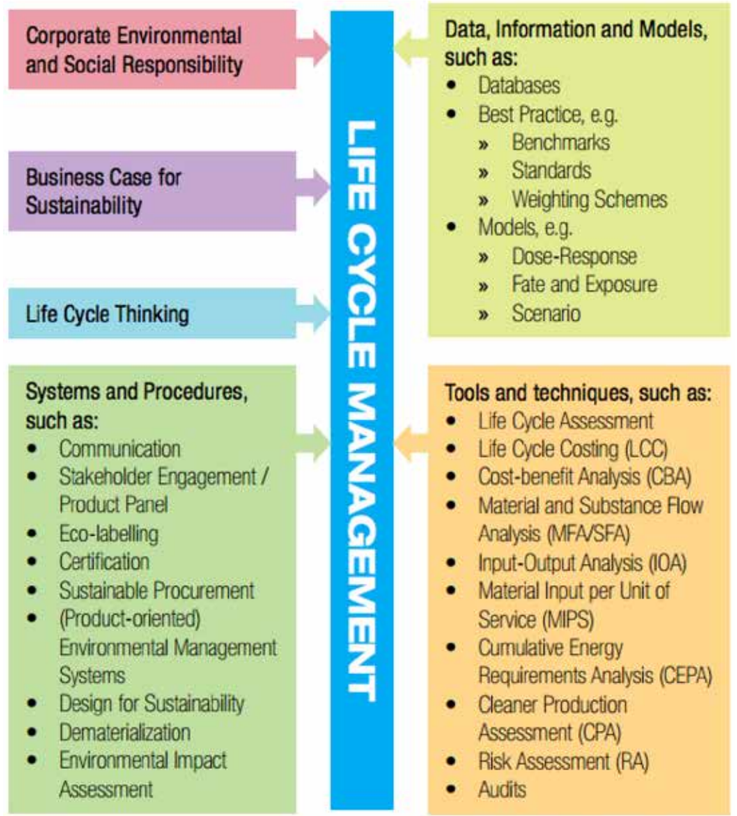
d) IO upstream GHG comparison

RESULTS

- outcome of the study lead to optimization of high volumetric efficiency capacitor selection for the power supply design based on performance / environmental fingerprint criteria
- target is not to “ban” one of the capacitor technology but prepare a more complex life assessment model of the power supply to evaluate different architecture design options
- the final power supply device can be offered including complete life cycle assessment figures to the automotive end user in order to evaluate its complete vehicle environmental impact

source: Smith, L., Ibn-Mohammed, T., Koh, S.C.L., Reaney, I.M. Life cycle assessment and environmental profile evaluations of high volumetric efficiency capacitors (2018) Applied Energy, 220, pp. 496-513. DOI: 10.1016/j.apenergy.2018.03.067

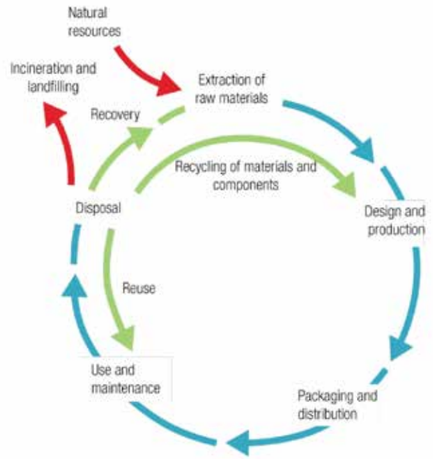
Sustainability & Life Cycle Management



Source: UNEP/SETAC. Life Cycle Management: A Business Guide to Sustainability. Paris, 2007.

Life Cycle Management (LCM) is an integrated concept for managing the total life cycle of goods and services toward a more sustainable production and consumption

…. LCM uses various procedural and analytical tools for different applications and integrates economic, social, and environmental aspects into an institutional context



Life Cycle Thinking is about going beyond the traditional focus on production site and manufacturing processes to include ***environmental, social and economic impacts of a product over its entire life cycle***

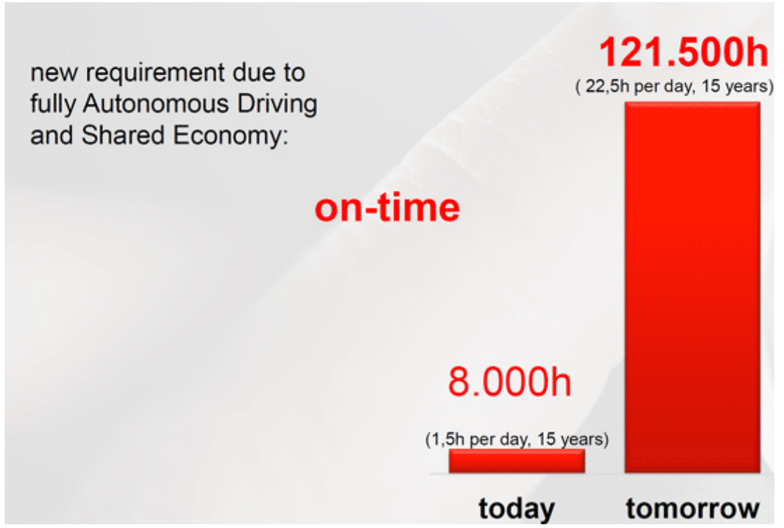
Reliability - Requirements

NEW REQUIREMENTS – SHARED ECONOMY & AUTONOMOUS DRIVING

RELIABILITY CONSIDERATIONS

is AEQ-200 the Sufficient Reliability Reference?

- **Automotive is becoming ultimate reliability standard** even for non-automotive applications (such as COTS space)
- AEC-Q200 capacitor reference condition requirements – 2000 hrs test at high temperature corner (85C). Is this sufficient for shared / autonomous systems ?
- Reliability Calculation – MIL standards and set acceleration factors (Arhenius) to give live prediction at application conditions. Are accelerating factors still valid for new materials and components ?

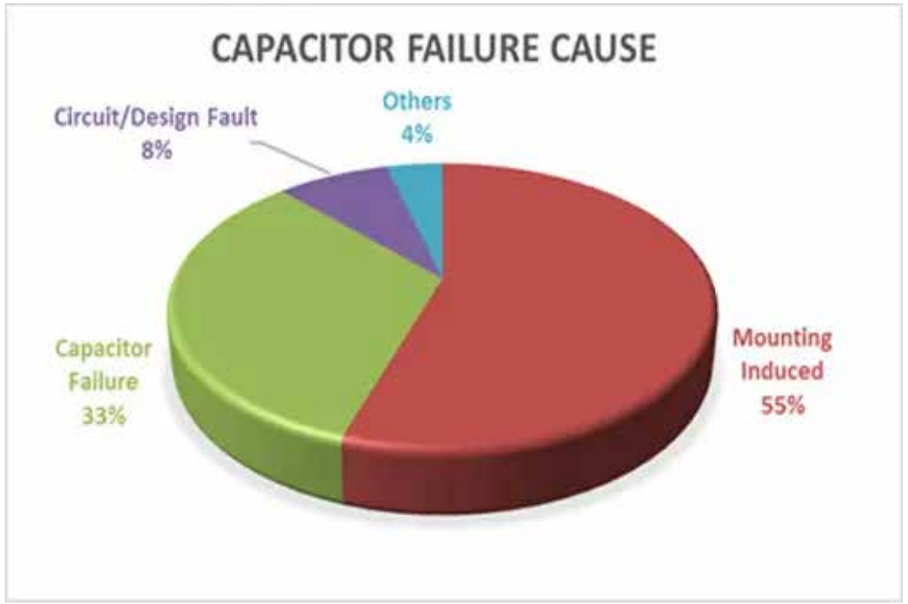


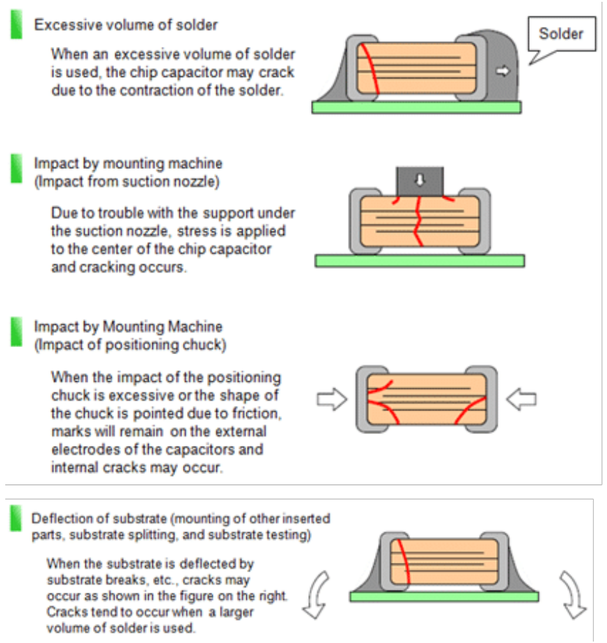
source: Wuerth Elektronik

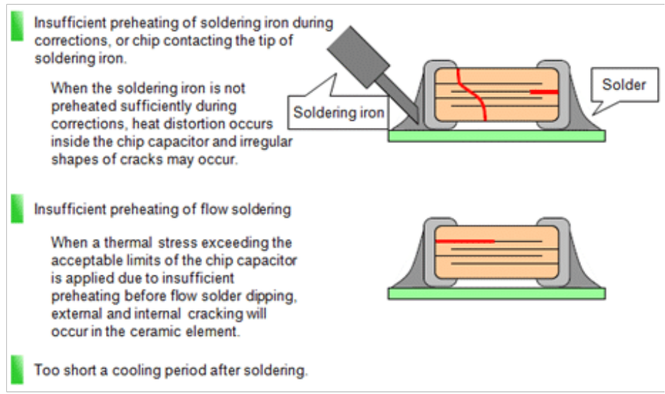
DISCUSSION

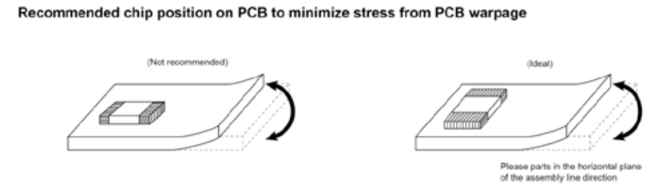
- Typical vehicle is most of its life-time parked in OFF mode, is the guaranteed life-time sufficient
- > 2000 hrs testing is not practical nor economical on manufacturer side
- Can we trust existing “old” reliability calculations / validity of acceleration factors for extended / new products.
- Some industrial applications operating close to real component corner continuous operation (85C) with requirements well exceeding 2000hrs life-time – mostly there is a lack of reliability data beyond 2K hours or physical models from component manufacturers to support life expectations**. Users have to rely on their own know-how relevant to the use of components in its specific application conditions.**

Complex Reliability – Reliability is NOT ONLY about Components !



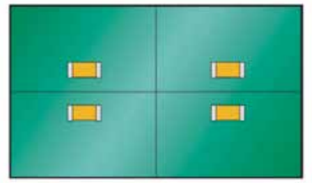


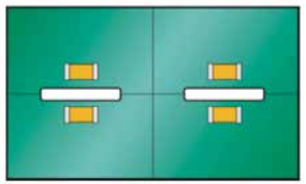




Mounting Induced Capacitor Failures

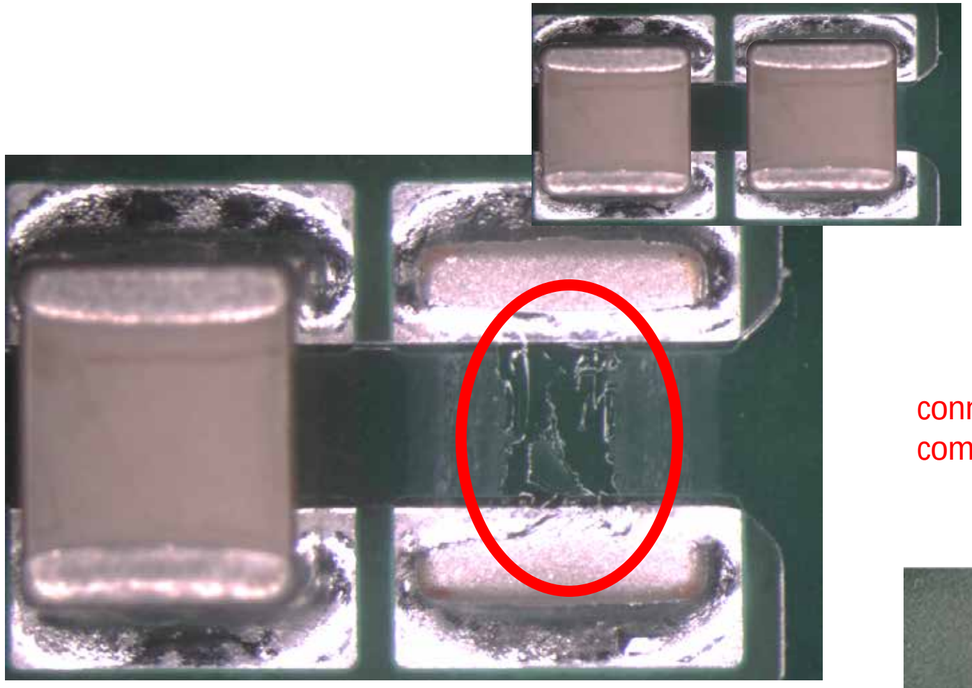
- Dominating capacitor failure cause
- Capacitor technology and application specific
- Driven by MLCC high volume capacitors assembly sensitivity
- Importance of manufacturer mounting recommendations & best practice rules
- New component types may raise new issues to be addressed

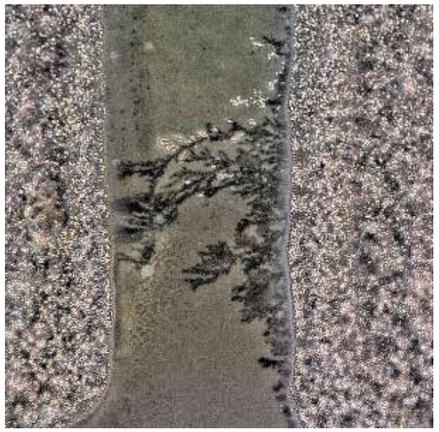

No Stress Relief for MLCs


Routed Cut Line Relieves Stress on MLC

source: Murata, EPCI

Complex Reliability – PCB Cleaning – Concern for High Reliability Apps



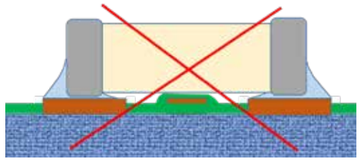


Pad Shortage Caused by Dendride Growth; source: PBT Works www.pbt-works.com

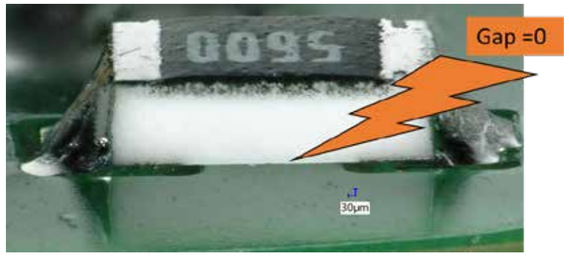
- “no clean” paste does not necessary mean NO CLEAN needed
- Cleaning challenges in thin gaps with limited wash fluid flow
- Length of channels (tunnels) is critical
- Cleaning issues / residual impurity reliability risk increase associated with PCB wrong layout and specific component types

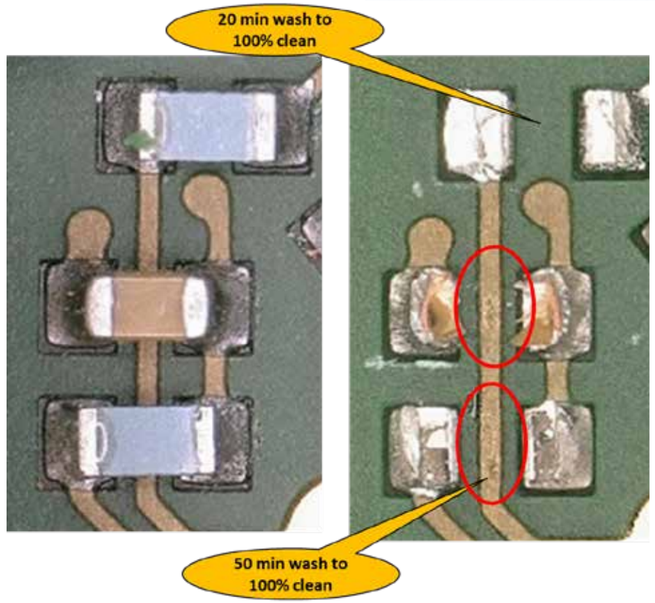
Clean Challenging PCB Pad Design Layout Examples

connection leads under components

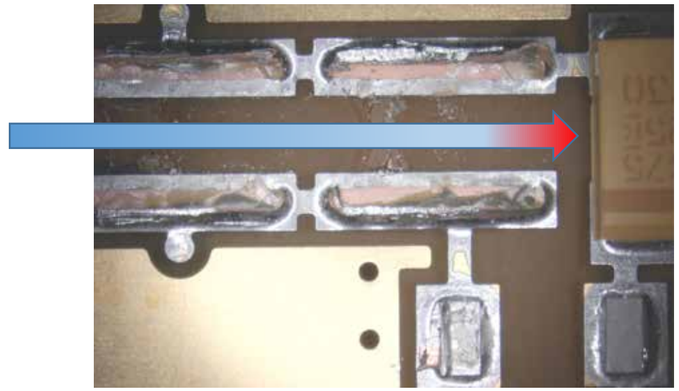


too thick solder mask





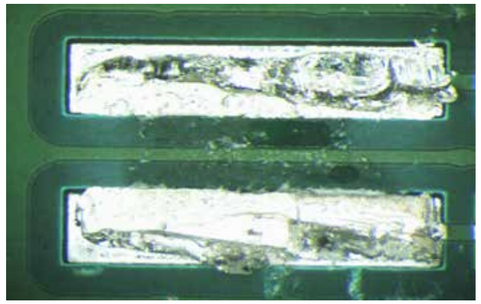
“T” blocked cleaning fluid flow

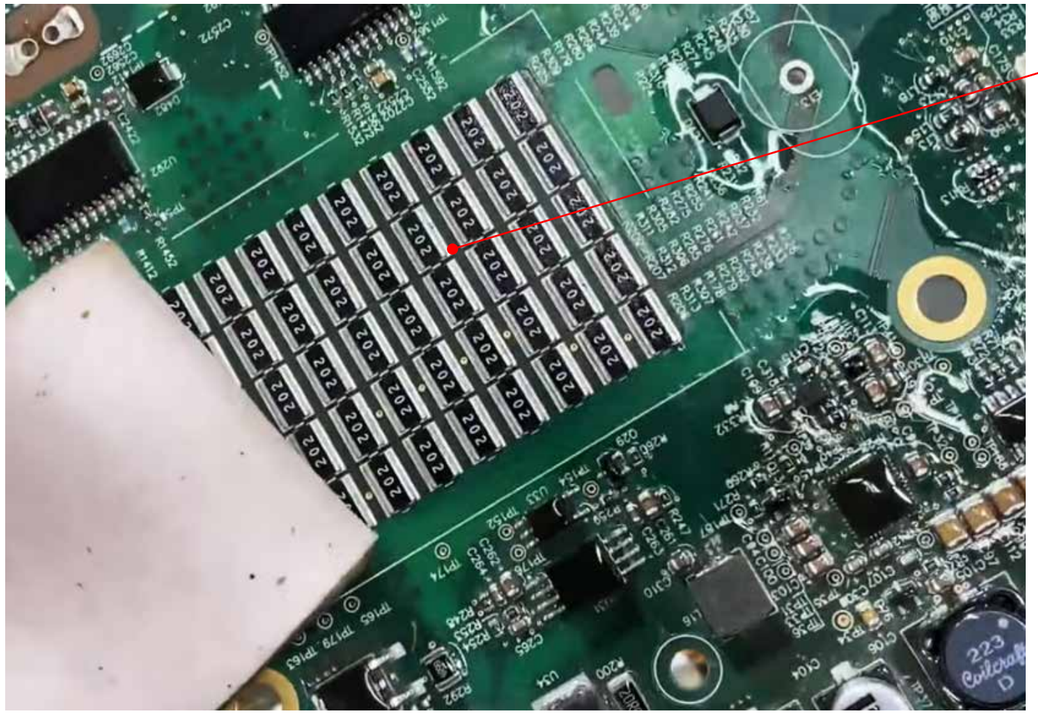


source: PBT Works www.pbt-works.com

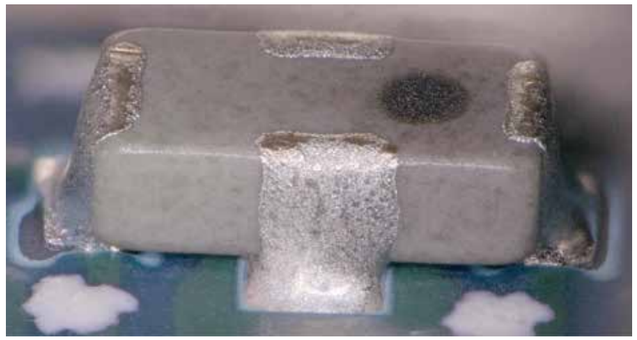
Complex Reliability – PCB Cleaning of Reverse and 3terminal Components

Reverse format Components good for heat dissipation, low ESL, mechanical robustness, but…. present cleaning challenges





3 terminal MLCC good for noise suppression, high frequency operation, low ESL but….. challenge to clean between 3 terminations



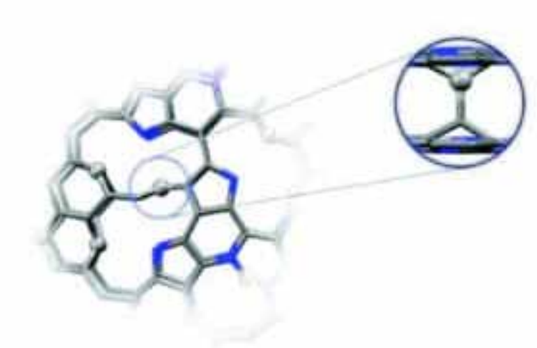
Automotive EV Specialist Inverter Board Bleeder Resistor
Reverse Geometry Resistor Network

VS.

- conventional EV manufacturer bleeder resistor design
- discrete component with manual assembly
- looks “less advanced” but “more robust”

NEXT GEN CAPACITORS

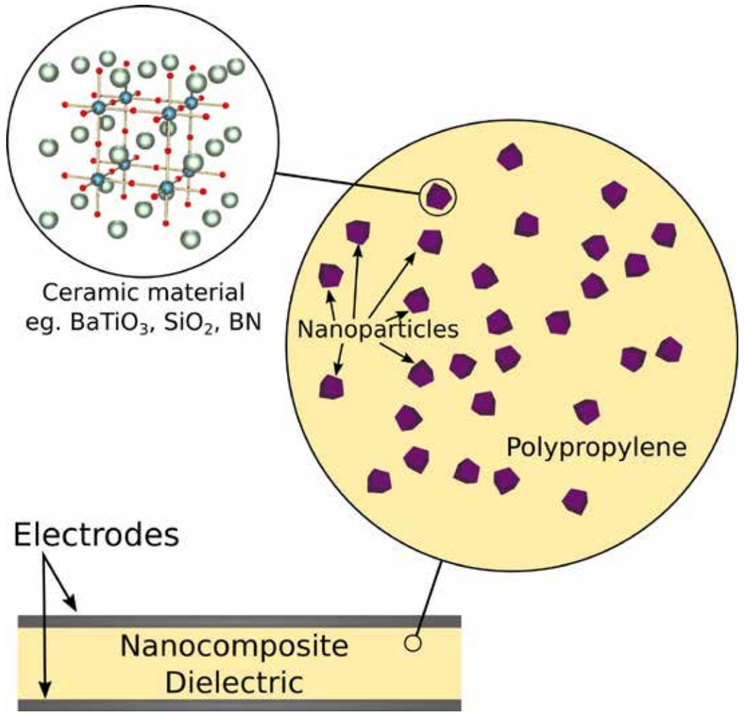
NEW **HIGH ENERGY DENSITY** MATERIALS & (NANO-)TECHNOLOGIES



New Materials – Nano-materials, Nano-Composites

Nano-Materials

Novel Nanocomposite Dielectric Material

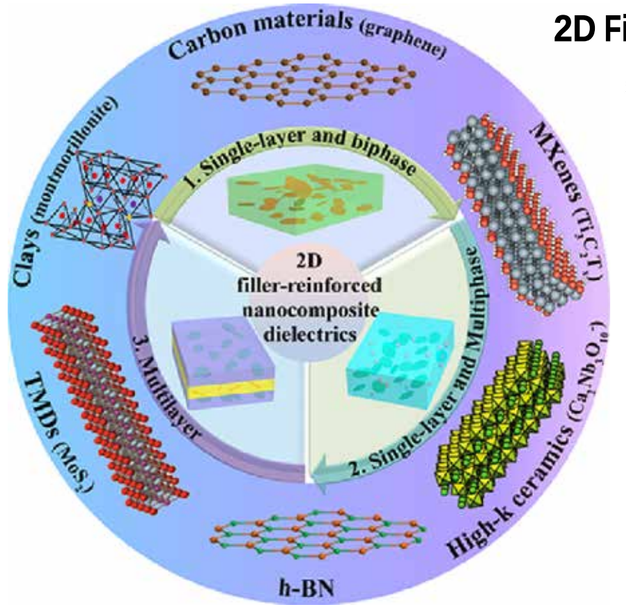


source: W.Greenbank at col., SDU Denmark

Mixed Dielectrics – Nanocomposite Dielectrics

- target to combine best features from different dielectric types
- metal oxide / ceramic material nanoparticles in polymer fillers
- 2D filler-reinforced carbon/graphene material based nanocomposite dielectrics
- not yet commercially successful as capacitor technology
- use of nanomaterials is promising approach to achieve homogenous-like novel dielectric materials

2D Filler-Reinforced Nanocomposite Dielectrics



source: Dalian University of Technology, China

Energy Storage Capacitors – Supercapacitors & Hybrids

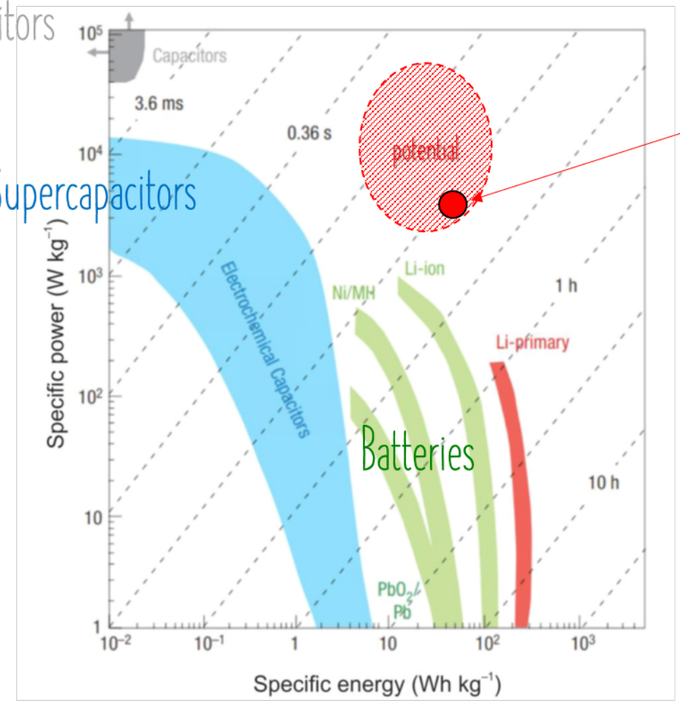
Graphene Based - Materials

Supercapacitors: from (active/nano) Carbon to Graphene

High Power & Energy Density Graphene Based Supercapacitors

Capacitors

Research Achievements

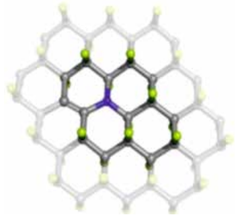


N-Doped 2D Graphene

ED up to 55 Wh/kg at PD 2 kW/kg

Potential:

ED 50-60 Wh/kg at PD 2-50 kW/kg



carbon atoms are grey

fluorine green

hydrogen white

nitrogen blue

Source: RCPTM Palacky University Olomouc, Czech Republic

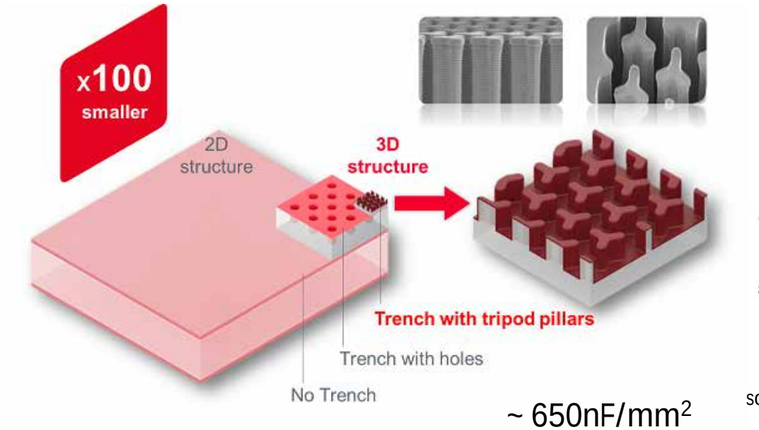
Power Of the Future:

- Small, Light, Cheap
- High Performance
- High Life Cycles
- Reliable
- Billions Made
- Sustainable

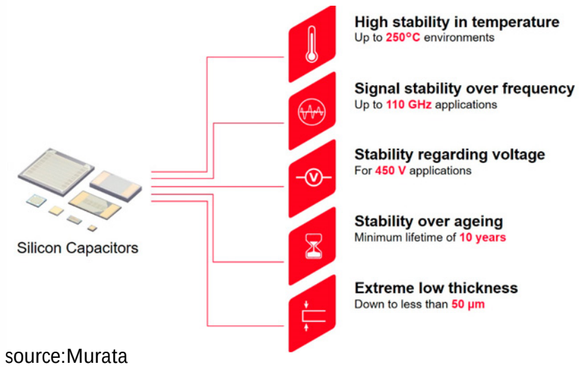
Integrated Capacitors – 3D Silicon, Wafer Based and CMOS Process Compatible

Integrated Capacitors

SiO_2 Dielectric Base (mass production stage)



~ 650nF/mm^2



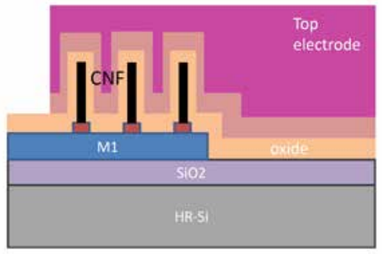
source:Murata

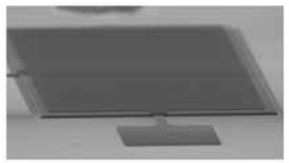
New Semiconductor Process For High Voltage Capacitors (MACOM)

source: Macom

- capable of achieving kilovolt (“KV”) operating levels in excess of 1,000 volts
- 200V, 500V and 1,000V, with capacitance values from 2 to 4,700 picofarads

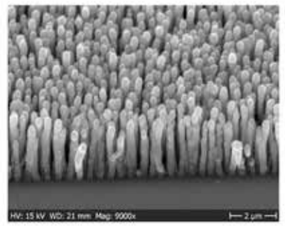
Carbon Nano Tube Base ALD Process Deposition of high K material (pre-production)





Conformal top electrode and bulk metallization

~ 650nF/mm^2

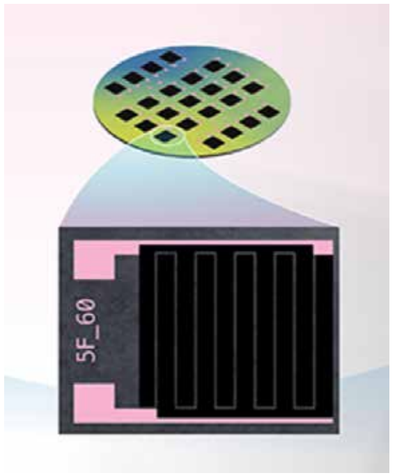


Conformal oxide deposition of HfO_2 and/or Al_2O_3 using ALD (< 250°C)

source: Smoltek, Sweden

Spin-Coated CMOS Compatible Microsupercapacitors for On-Chip Low Power Electronics (research)

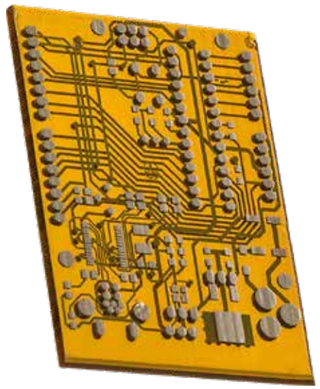
~ 1mF/mm^2

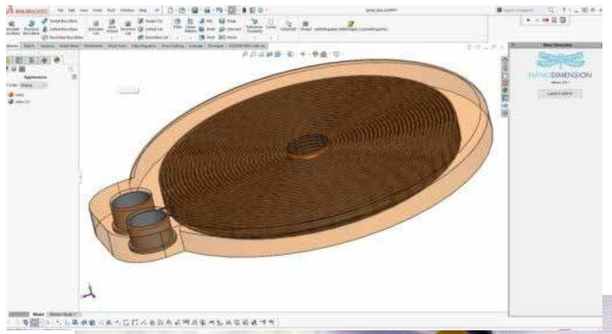


source: Chalmers University, Sweden

3D Printed Components / Electrodes

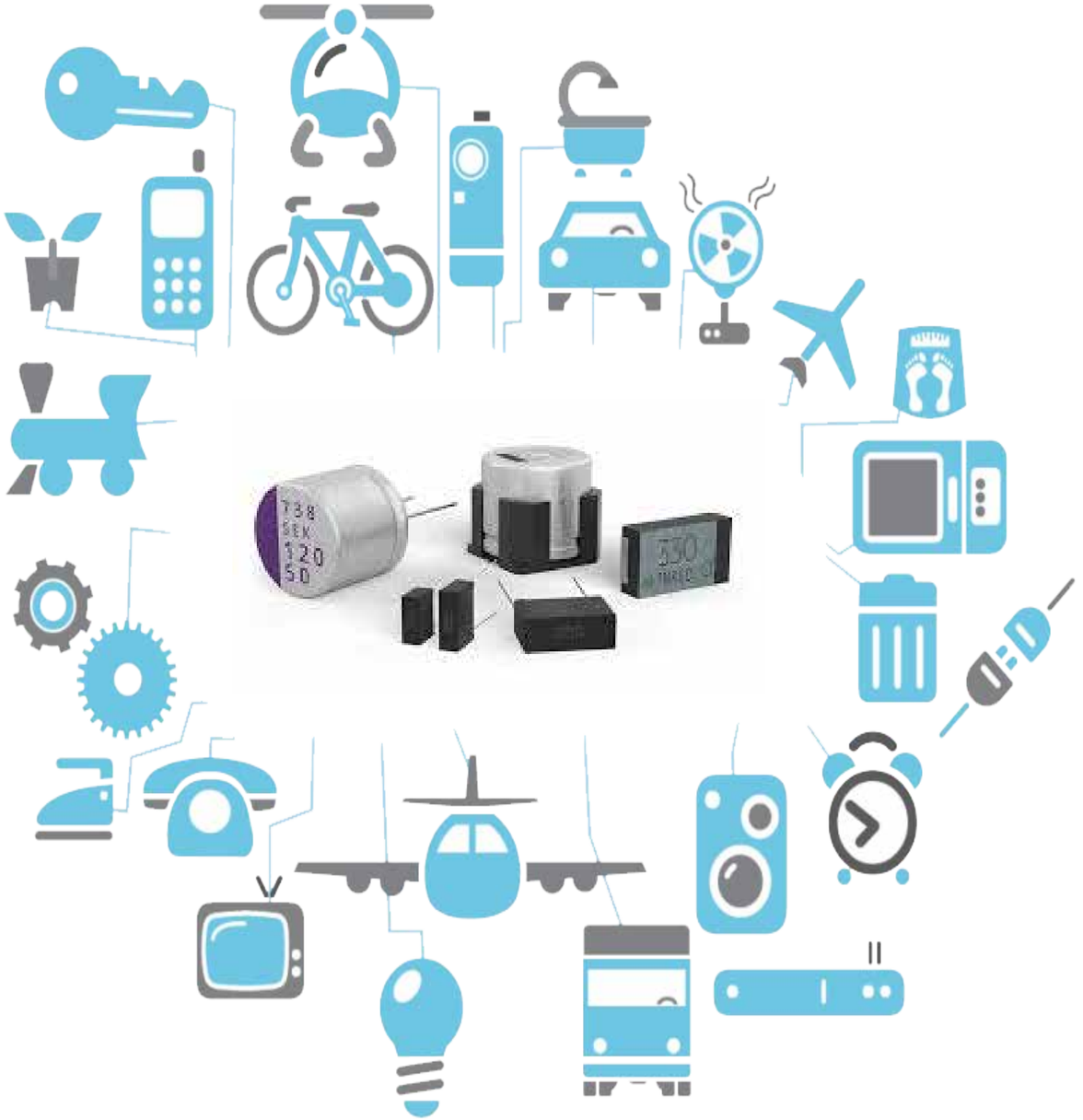
- separate conductive and dielectric inks deposition and curing
- FR4 like dielectric and silver inks available now, further in R&D
- min dimension between conductive path: 125





Source: https://passive-components.eu/when-are-we-going-to-print-pcbs-on-3d-printer-ourselves/

SUMMARY & CONCLUSION



SUMMARY & CONCLUSION (1 of 2)

Materials

materials are becoming the central point for many aspects of future component designs

(i) complete supply chain and material selection evaluation in order to assess its critical chain, complete life cycle and reduce its environmental footprint.

(ii) understanding of material properties, **its basic physics mechanisms** are the key for failure mechanisms assessment and reliability predictions

(iii) nano-material science may yield in development of completely new generation of modern dielectric materials

2022 Critical Supply Chain Management

Components End User Design-in Response:

- Design based on what may not be the best fit but what is available
- Components supply chain and bottlenecks shall be re-evaluated

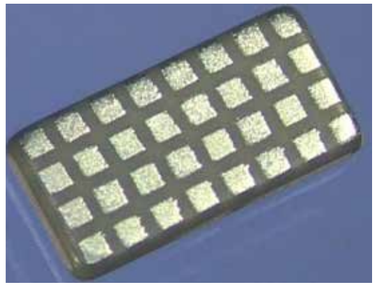
SUMMARY & CONCLUSION (2 of 2)

NEXT GENERATION CAPACITORS

- Evolution is not developing linearly but in step-up strikes
- Material supply chain disruption may drive design Innovation

Need for efficient components is growing evolution driven by:

1) IC Semiconductor Demands
2) New Applications & Automotive
3) Emerging Active/Passive Technologies & Packages
4) Sustainable Development



EPCI European Passive Components Institute

4th PCNS

11-14th September 2023

SDU Sønderborg, Denmark

- International conference on Passive Components
- Bi-annual event hosted by European university
- 4th PCNS 2023 hosted by SDU University
- Intended as LIVE event

PC 2 NS 3
11-14th September
Sønderborg, Denmark

Theme (tentative): **Materials & Supply Chain of Passive Components**

The theme will be elaborated in conference Workshop, Hot Topic Panel Discussion, Keynote and papers selection preferences.

- **1st Feb 23 Call for Papers**
- 2 Apr 23 Abstract deadline
- 31 Apr 23 Notice of acceptance
- 9 Jun 23 Paper deadline
- 16 Jun 23 Preliminary programme
- 16 Jun 23 Early registration up to
- 23 July 23 Final programme
- **11-14 Sep 23 Conference dates**

TOPICS

- MATERIALS & PROCESSES
- DESIGN & CONSTRUCTION
- MEASUREMENT & TEST
- QUALITY & RELIABILITY
- TECHNOLOGY & ROADMAPS
- APPLICATIONS
- NEW DEVELOPMENT
- MODELLING & SIMULATION

COMPONENTS

- CAPACITORS
- INDUCTORS & TRANSFORMERS
- RESISTORS
- FUSES
- FILTERS
- RF PASSIVES
- PASSIVE SENSORS
- CONNECTORS & CABLES
- CRYSTALS & OSCILLATORS

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