TRANSITION OF THE GERMAN TRANSPORTATION INDUSTRY, INTERNET OF THINGS AND THE ROLE OF SMART MATERIALS

Industrial Nanocomposites Conference 2017

10 Oct 2017 - 11 Oct 2017, Maritim Hotel, Stuttgart, Germany

Ivica KOLARIC Fraunhofer IPA

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Technology consultant and innovation driver since 1959

- Operational budget of 70.8 million euros
- 25.8 million euros in industrial revenues
- More than 1,000 employees

New technical center "Gebäude D" in Stuttgart

Fraunhofer Institute Center in Stuttgart

Note: key figures for 2016; IPA Stuttgart including locations in Rostock, Mannheim, Bayreuth and Vienna

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ELEMENTS OF A SMARTPHONE

ELEMENTS COLOUR KEY: ALKALI METAL | ALKALINE EARTH METAL | TRANSITION METAL | GROUP 13 | GROUP 14 | GROUP 15 | GROUP 16 | HALOGEN | LANTHANIDE

SCREEN

49 In Indium
50 Sn Tin
8 O Oxygen

Indium tin oxide is a mixture of indium oxide and tin oxide, used in a transparent film in the screen that conducts electricity. This allows the screen to function as a touch screen.

13 Al Aluminium
14 Si Silicon
8 O Oxygen
19 K Potassium

The glass used on the majority of smartphones is an aluminosilicate glass, composed of a mix of alumina (Al_2O_3) and silica (SiO_2). This glass also contains potassium ions, which help to strengthen it.

39 Y Yttrium
57 La Lanthanum
65 Tb Terbium
59 Pr Praseodymium
63 Eu Europium
66 Dy Dysprosium
64 Gd Gadolinium

A variety of Rare Earth Element compounds are used in small quantities to produce the colours in the smartphone's screen. Some compounds are also used to reduce UV light penetration into the phone.

ELECTRONICS

Copper is used for wiring in the phone, whilst copper, gold and silver are the major metals from which microelectrical components are fashioned. Tantalum is the major component of micro-capacitors.

29 Cu Copper
47 Ag Silver
79 Au Gold
73 Ta Tantalum

Nickel is used in the microphone as well as for other electrical connections. Alloys including the elements praseodymium, gadolinium and neodymium are used in the magnets in the speaker and microphone. Neodymium, terbium and dysprosium are used in the vibration unit.

28 Ni Nickel
66 Dy Dysprosium
59 Pr Praseodymium
65 Tb Terbium
60 Nd Neodymium
64 Gd Gadolinium

Pure silicon is used to manufacture the chip in the phone. It is oxidised to produce non-conducting regions, then other elements are added in order to allow the chip to conduct electricity.

14 Si Silicon
8 O Oxygen
51 Sb Antimony
33 As Arsenic
15 P Phosphorus
31 Ga Gallium

Tin & lead are used to solder electronics in the phone. Newer lead-free solders use a mix of tin, copper and silver.

50 Sn Tin
82 Pb Lead

BATTERY

3 Li Lithium
27 Co Cobalt
8 O Oxygen
6 C Carbon
13 Al Aluminium

The majority of phones use lithium ion batteries, which are composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Some batteries use other metals, such as manganese, in place of cobalt. The battery's casing is made of aluminium.

CASING

Magnesium compounds are alloyed to make some phone cases, whilst many are made of plastics. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.

6 C Carbon
12 Mg Magnesium
35 Br Bromine
28 Ni Nickel

The Future of Materials
New super alloys and electronics

- **Rising demand for electronics**
  - sensor materials
  - conductive materials
  - materials for semiconductors
  - High capacity materials
- **High productivity mining**
  - Lithium
  - Phosphor
  - Indium
  - … …
- **New Super Alloys**
  - 60 Materials used => 10 Exp 70 potential alloys

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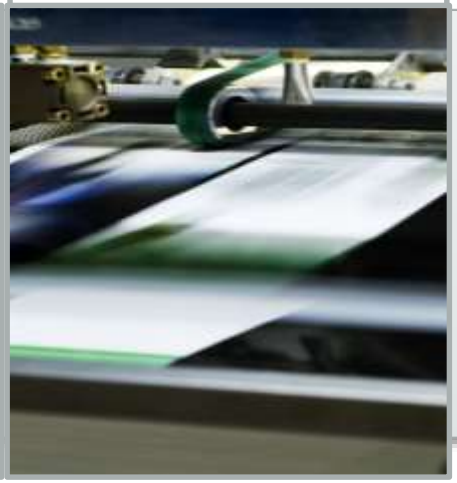
One Stop Shop in Printed Functionalities

Synthesis and functionalization

Dispersion Technology

Application Technology



Data management & Simulation

Efficient management of resources

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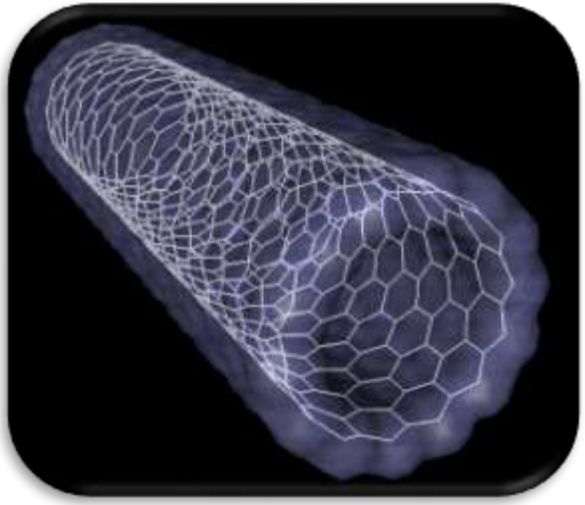

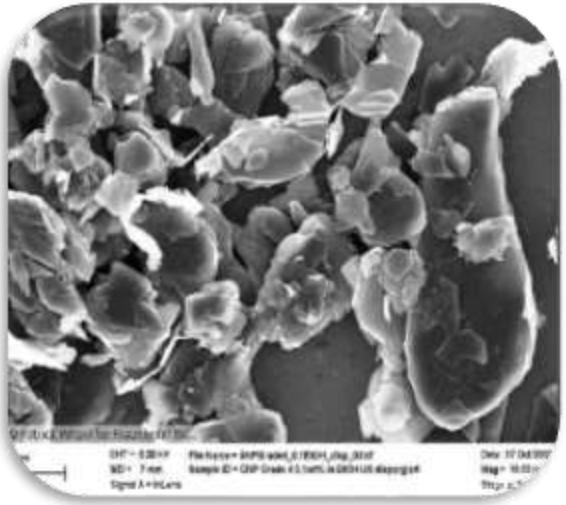

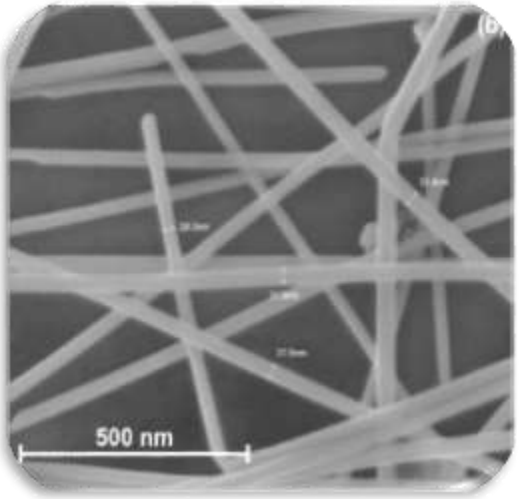

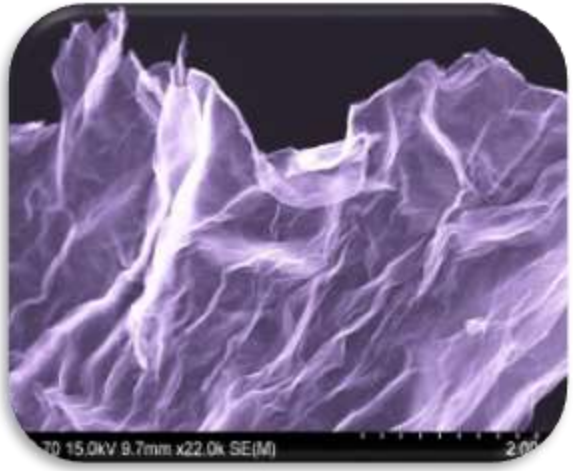

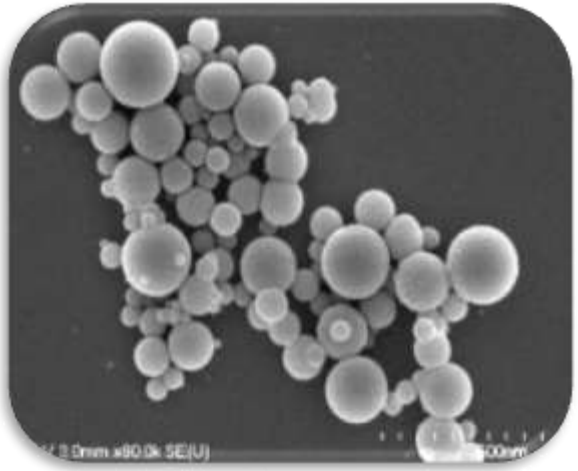

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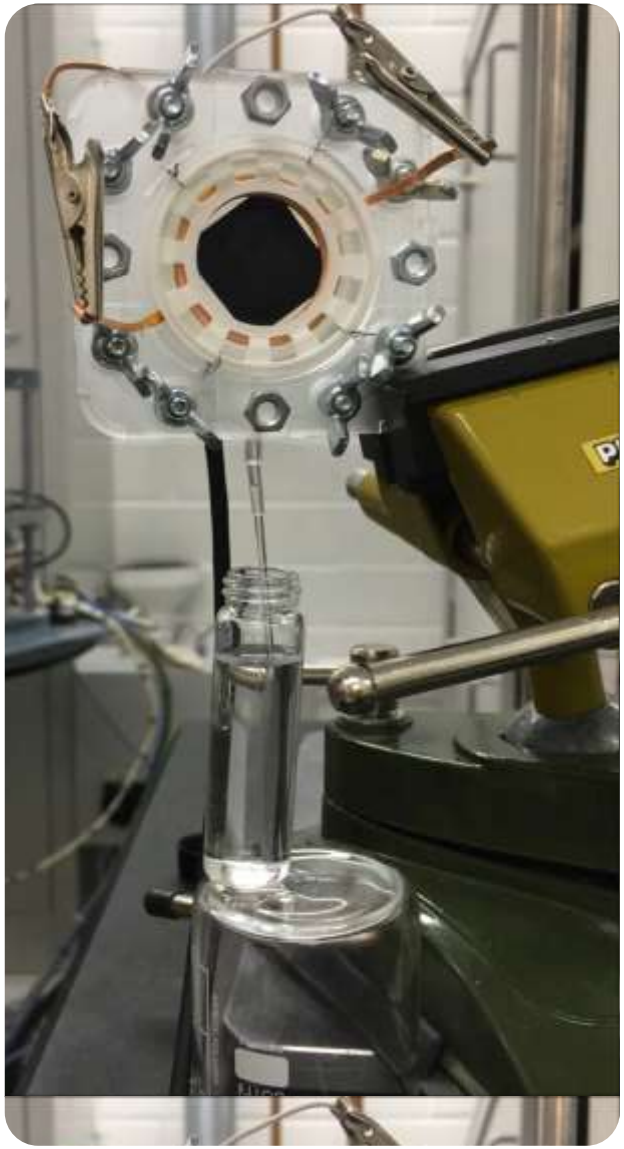
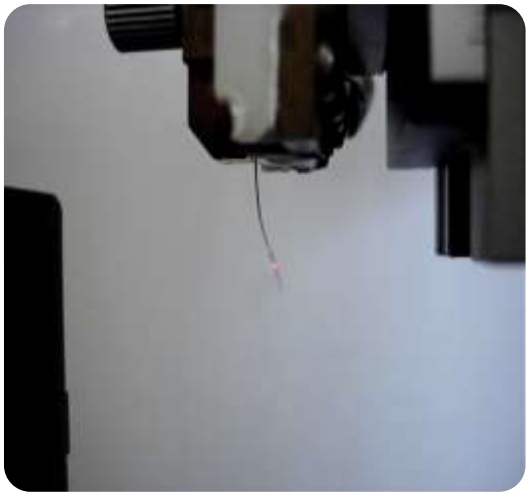
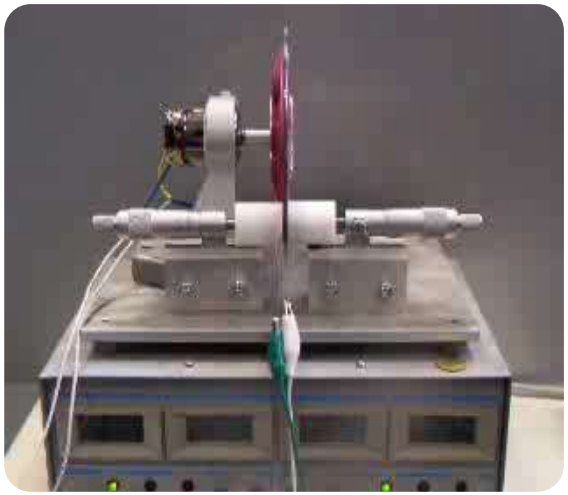
History of Fraunhofer IPA's Research on Functional Materials







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Stuttgart, Germanys Center of Automotive

- 1.366 bill.€ turnover worldwide
- 76 mil. cars sold worldwide
- Annual turnover of German OEMs: 412 bill. € (German GDP: 3,000 bill.€)
- Every 6th €-earned in Germany is related to cars
- Every 4th job in Baden-Württemberg
- Every 2nd in Stuttgart area
- 80% of Germany Automotive Production 200km around Stuttgart

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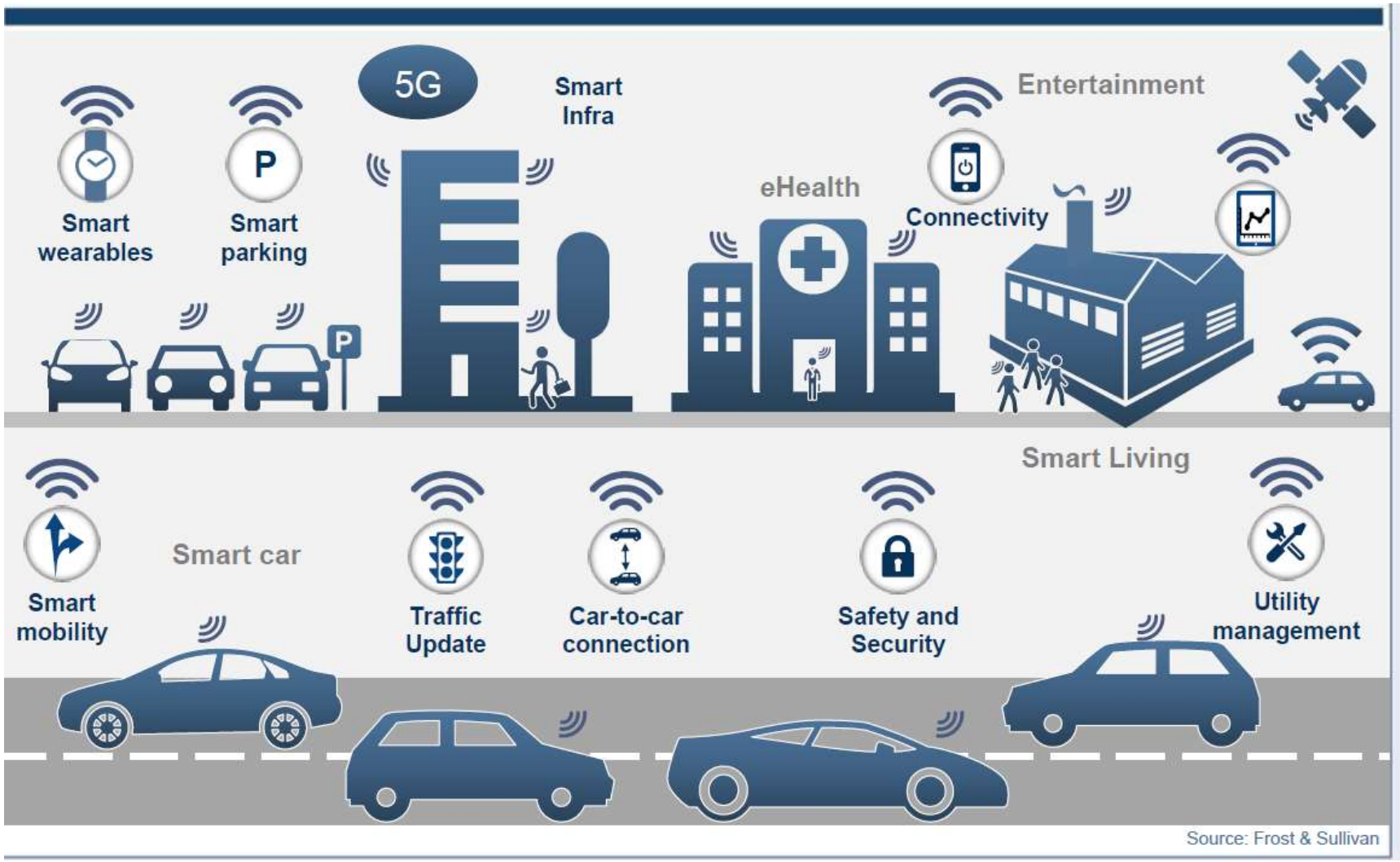

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Current Level

2011	2016	2018	2025	2030
No Assist	Early Warning Systems	Traffic Control	Awareness for Takeover	General Awareness	Full Autonomous Driving
Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
New Vehicles	40 million	15 million	5 million	2 million	1 million

Source: Frost & Sullivan

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Urbanisation Impact on Vehicle Technology Planning

Opportunity for OEMs to Develop Technologies for Unmet Customer Needs

Mega City Cars

- CO_2 less than 80 g/km vehicles
- Voice-recognition technology
- Start-stop system for frequent stops in traffic
- Customised and personalised comfort functions
- Autonomous parking assist
- Simple and easy-to-use HMI
- Ergonomically designed, comfortable seats for long commuting hours
- Turning radius <4.3m to drive in congested streets
- Smart vehicle access

- Vehicle length of less than 3,500 mm
- Limited boot space and more head and leg room
- Panoramic roofs
- Lightweight construction
- Low-speed collision avoidance for enhanced safety and pedestrian protection
- 3G/Wi-Fi Connectivity - V2V and V2X communication
- Facebook on wheels, Internet in cars
- Navigation systems with route guidance and traffic information

Source: Frost & Sullivan analysis.

Source: Frost & Sullivan analysis

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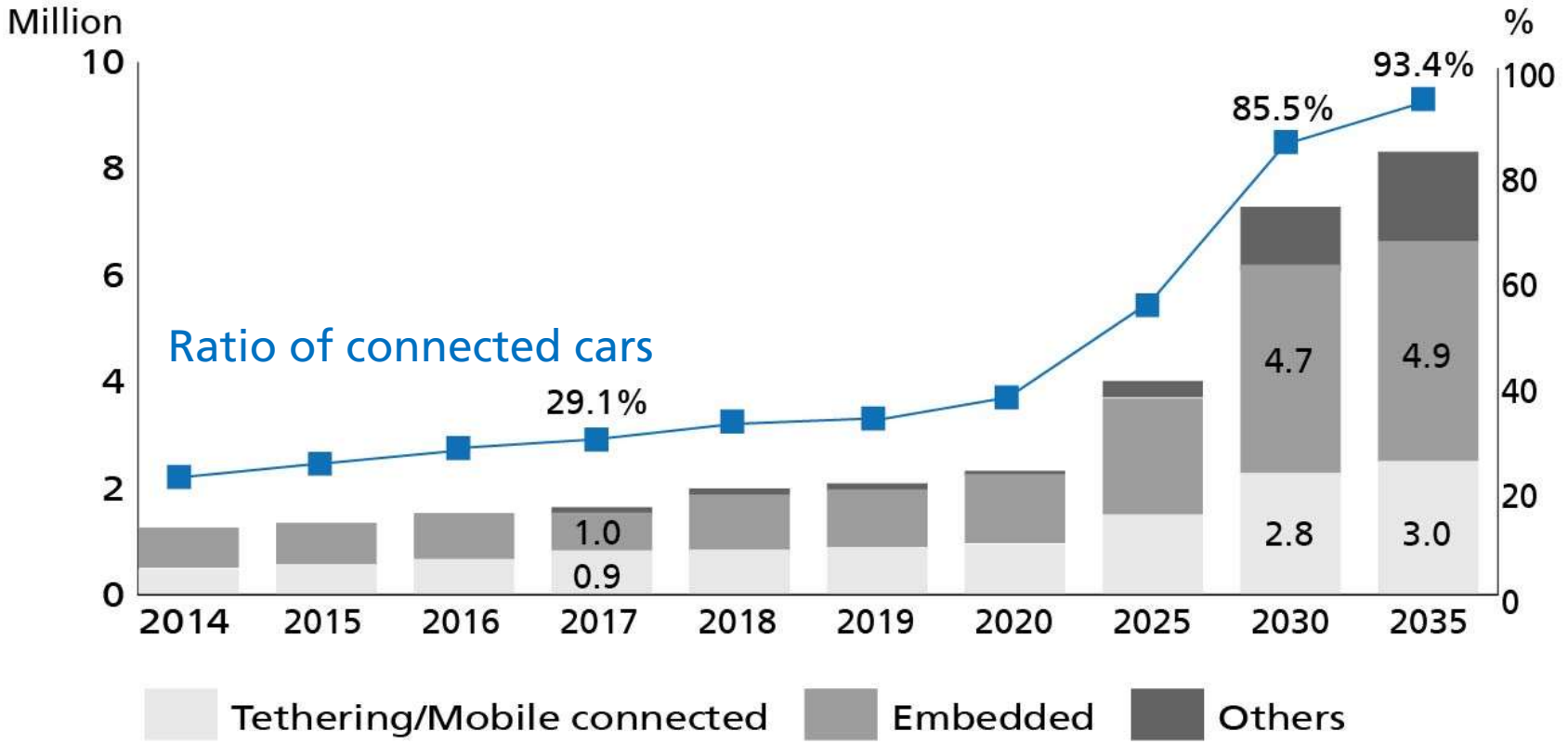
Connected car world market forecast (2035) (based on new auto sales)



Source: Fuji Keizai, March 2017

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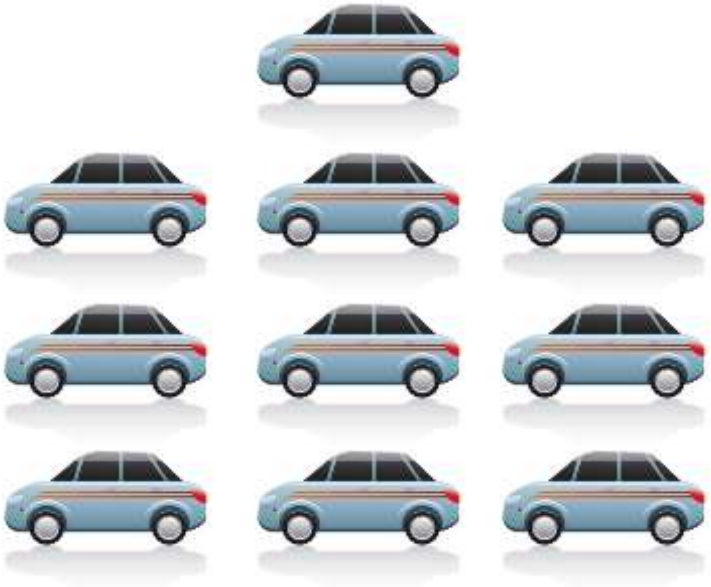
TODAY



TOMMOROW

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TODAY

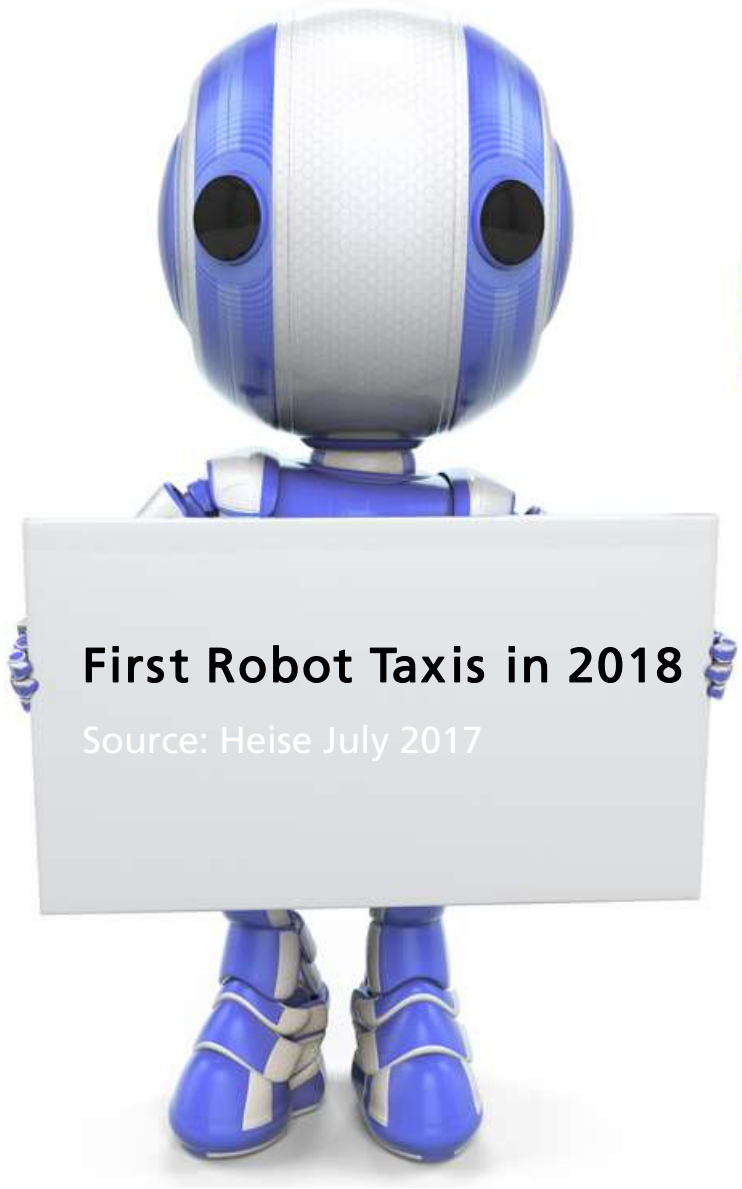
17.100.000 T / p.a

Source (Handelsblatt „Stahl bleibt wichtigster Werkstoff“ September 2005

TOMMOROW

1.710.000 T / p.a

- 15.000.000 T/p.a



First Robot Taxis in 2018

Source: Heise July 2017

Mercedes-Benz

BOSCH

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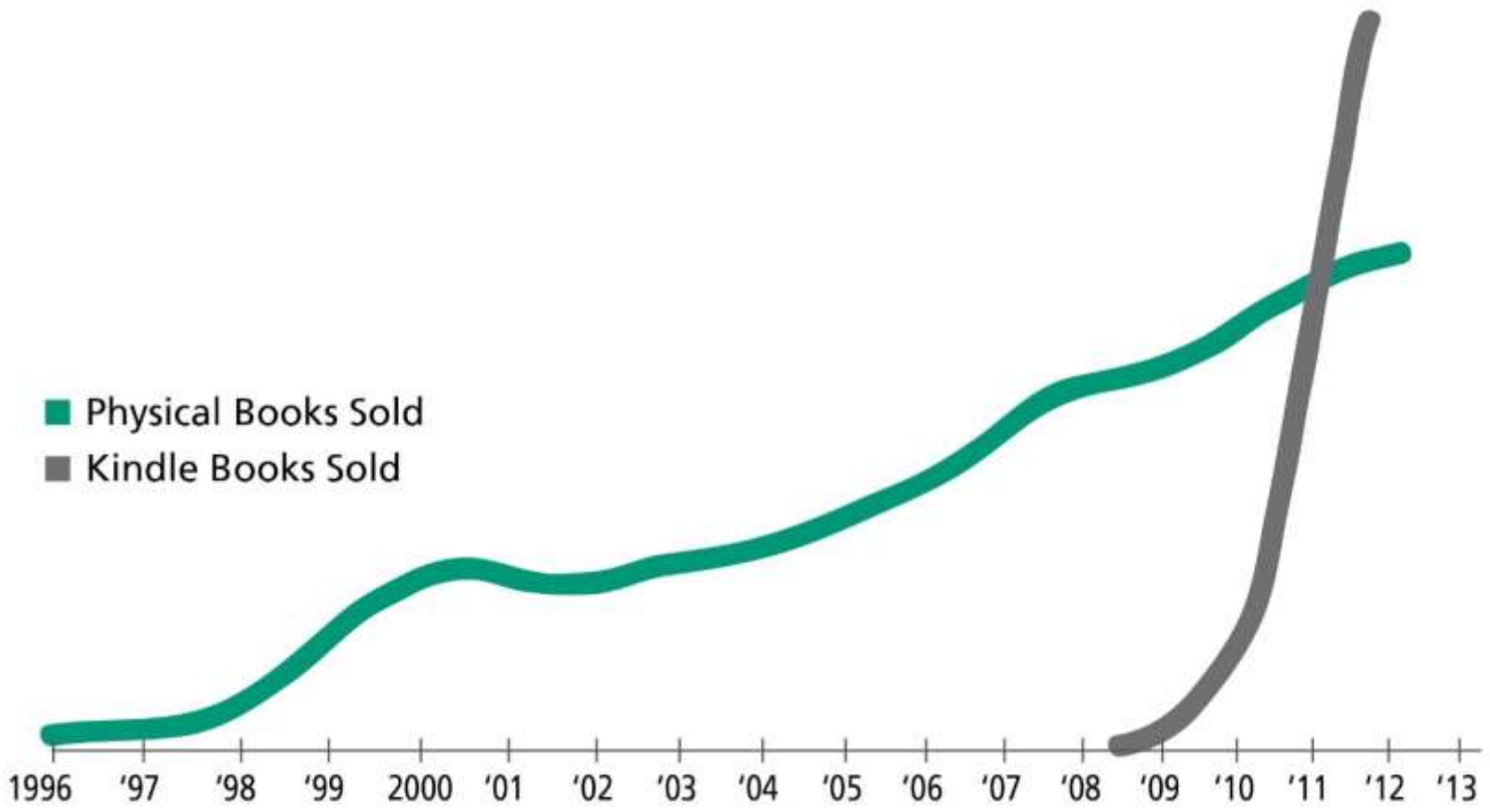
Physical Books Sold vs. Kindle Books Sold



Source: Amazon via The Verge (9/06/12), Silicon Alley Insider

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HYPOTHESES FOR AUTOMOTIVE INDUSTRIE 2030

- The Production will move to their markets
- The Number of shared car's will rise significantly
- The Number of Electro Vehicles will rise
- Rising Demand for connectivity solutions
- Usage of Multi materials

Nano Materials in Automotive Industries

Future Spheres of Activity of Nanomaterials

// PRODUCTION //

// LIGHTWEIGHT DESIGN //

// ENERGY STORRAGE //

// HUMAN MASCHINE INTERFACES //

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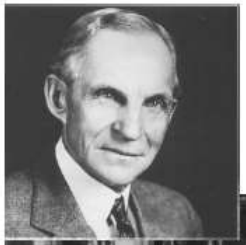
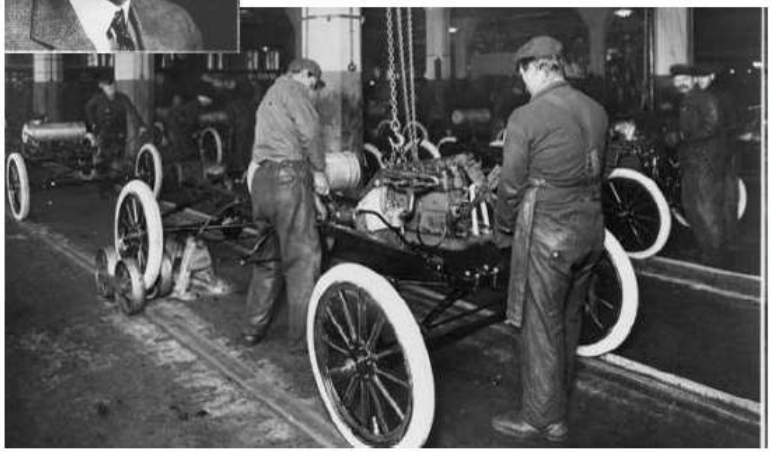
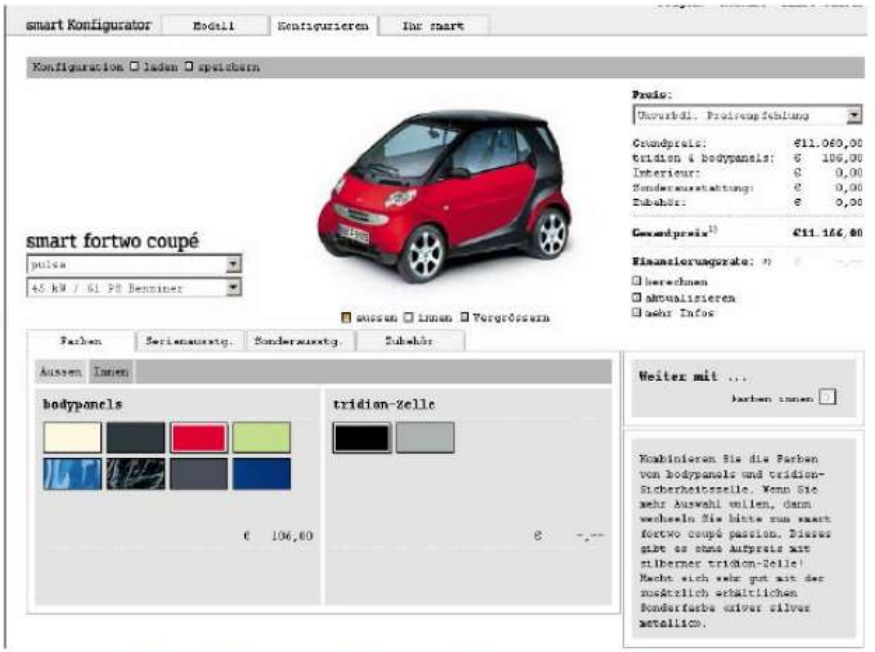
Gestern



„any colour you want, as long as it´s black“



Heute



Make to stock

1 Variante

Online Konfigurator

Rechnerisch:
32.000 Türinnenverkleidungen (Audi A8)
10^8 Varianten Gesamtfahrzeug

Source : BVL

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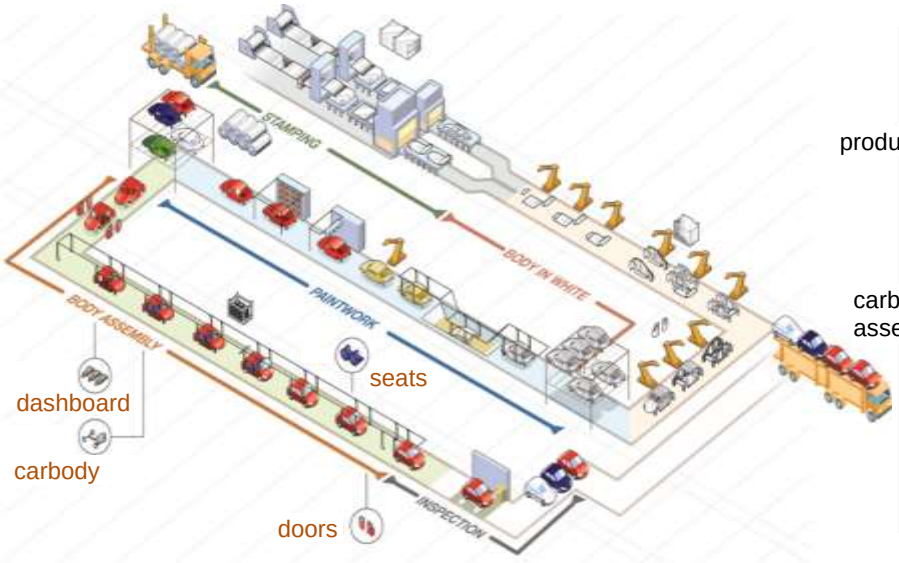
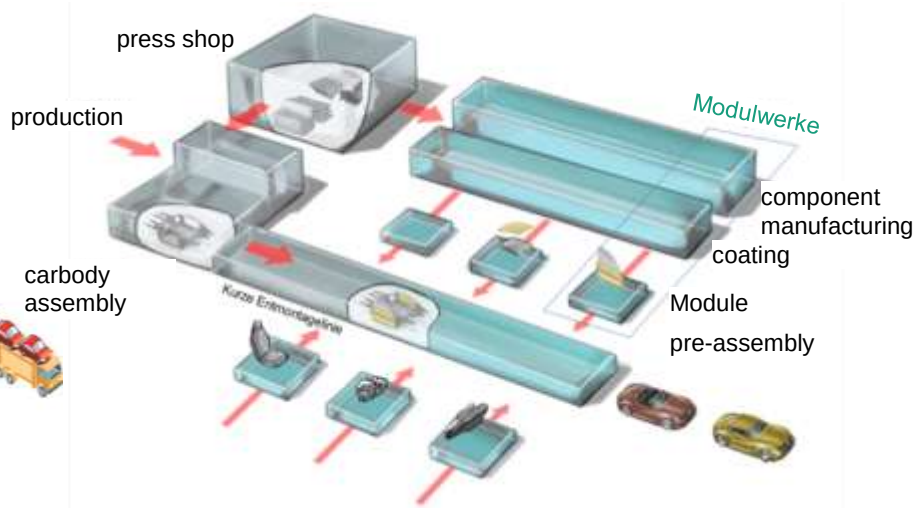
ARENA2036

Freely Accessable Process Modules for (Automotive)Production of the Future

Today



Arena 2036



Challenge

- Decomposing traditional processing line without the disadvantages of classical workshops
- Changeability creates additional complexity

Objects in a Factory will become smart and very agile

Example: swarm intelligence for logistics

source: Fraunhofer IML, Prof. Dr. Michael ten Hompel

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What is the goal of ARENA2036? – Vision

The demand for sustainability and individuality radically changes the products and production environment of tomorrow. ARENA2036 focuses on these fields of technology:

Automobile2036:

- Multi-material lightweight design by functional integration
- New materials and joining technologies
- Continuous digitalization of all processes
- Vehicle concept for autonomous and crashless cars

Production2036:

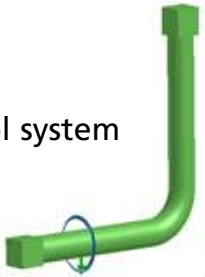
- Versatile production
- Industry 4.0 research and implementation
- Humans in the factory of the future
- Micro Factories

Industry 4.0 from development to production

Automobile research meets the demand for more vehicle variability and comfort by combining lightweight engineering and versatile production.

The supply chain and all stages of the process chain are subject to change.

DigitPro: Virtual process chain



Robot control system

CAM (NEW!)
(HDF5-Standard)

Material modelling

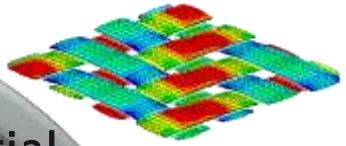
DIGITAL PROTOTYPE

Process simulation

Structure simulation & testing

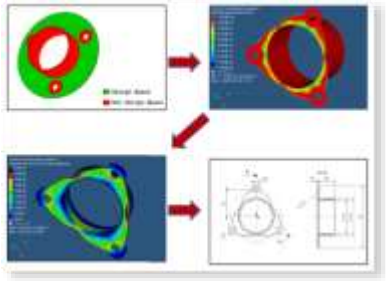
Optimizing

-50% development time
-10% weight

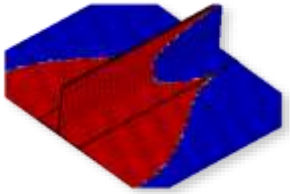


Micro- and meso-level model

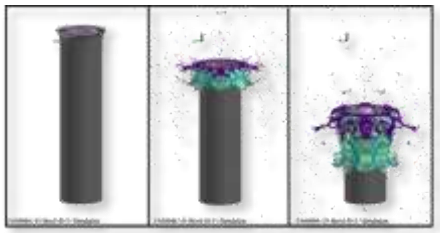
Draping simulation



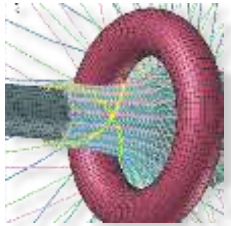
Load path optimizing



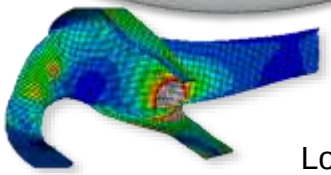
Virtual infiltration



Crash simulation



Braiding simulation



Load analysis

All process steps are simulated and get validated by tests. This will enable the use of FRP's (fiber-reinforced plastic) and multi-materials for industrial use.

A short summery

- Devices and Parts will turn be „smart“
- Robot will collaborate with Robots, Tools and People

LIGHT WEIGHT DESIGN

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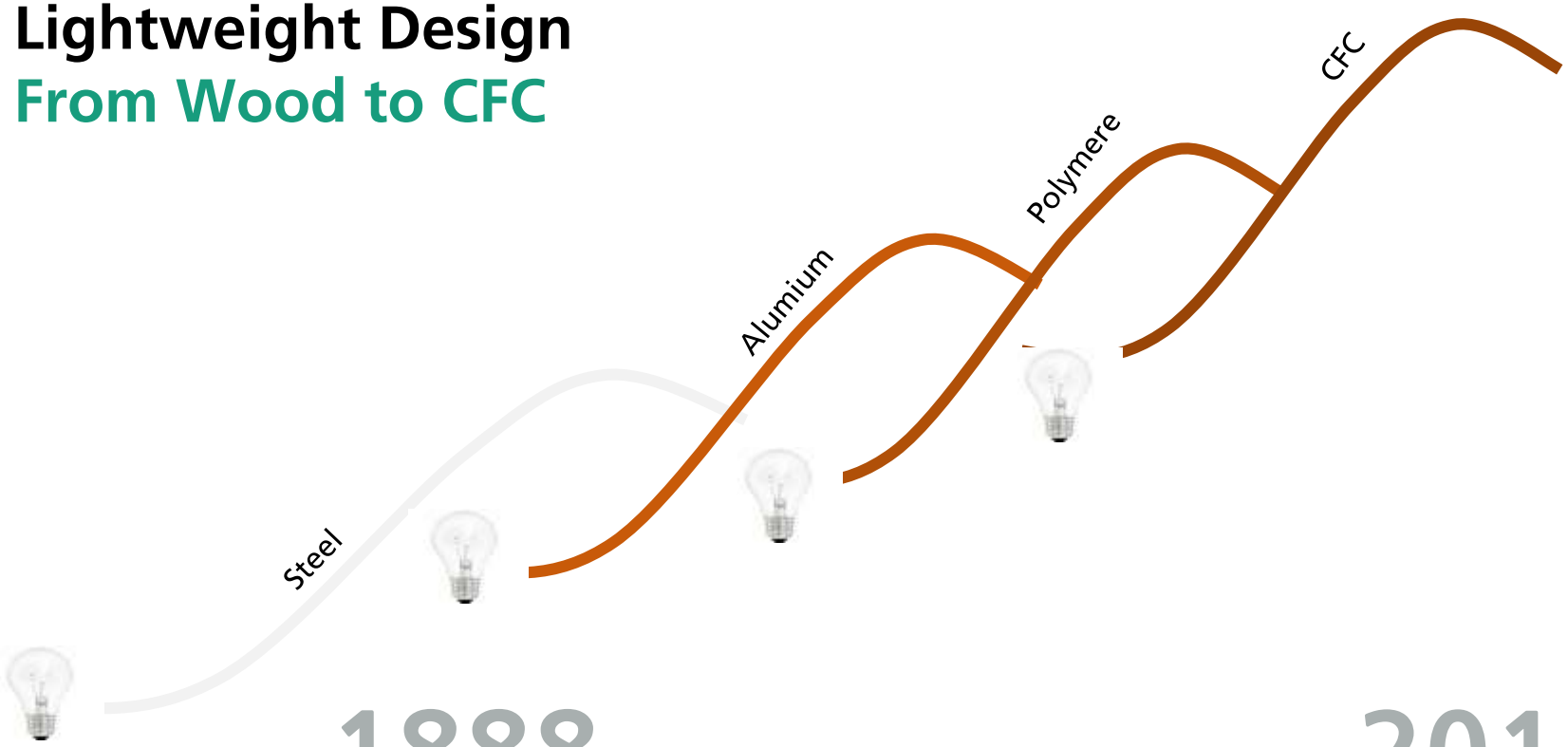
Lightweight Design
From Wood to CFC



1888

2013

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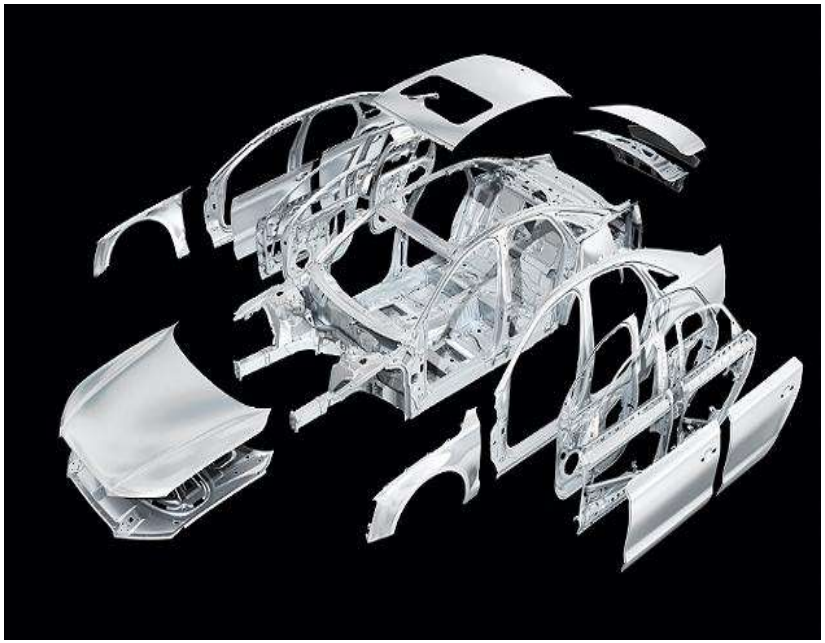
Lightweight Design
Multimaterial Space Frame (MSF) by Audi

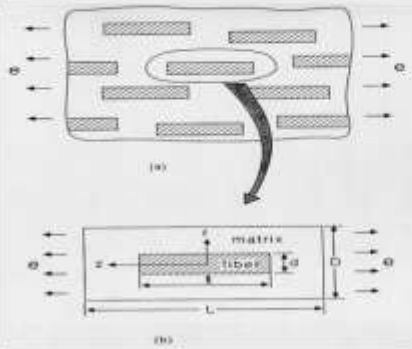
- Connection of metal (Al / Steel) and / or Carbon (CFK) structures
- Better mechanical structure and better deformation behavior
- Connection of both materials, form- or force fitted
- Development of new processes, like RTM: Resin Transfer Moulding



Source: AUDI AG

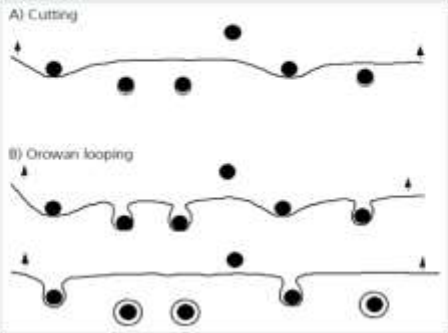
Lightweight Design
Principles of Nano reinforcement

Thermal mismatch*1



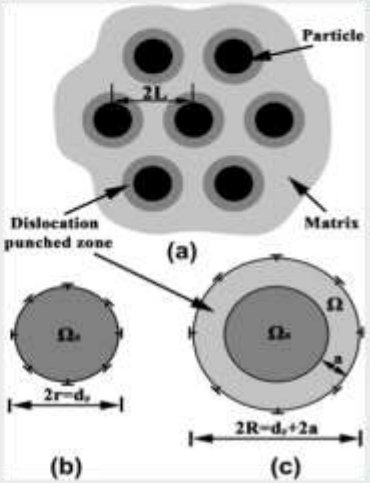
- Hardening of the matrix
- Al matrix high, CNT low
- Prismatic punching of dislocations

Orowan looping*2



- Increase in yield strength
- Stop dislocation movement

Shear lag*3



- Increase in stiffness (E Mod)
- Transfer of load from the matrix to reinforcement

*1: Arsenault RJ, Shi N. Mater Sci Eng 1986;81:175.
*2: Orowan E. Z, Phys 1934;89:634
*3: Clyne TW, An Introduction to Metal Matrix Composites. Cambridge University Press; 1995. p. 26

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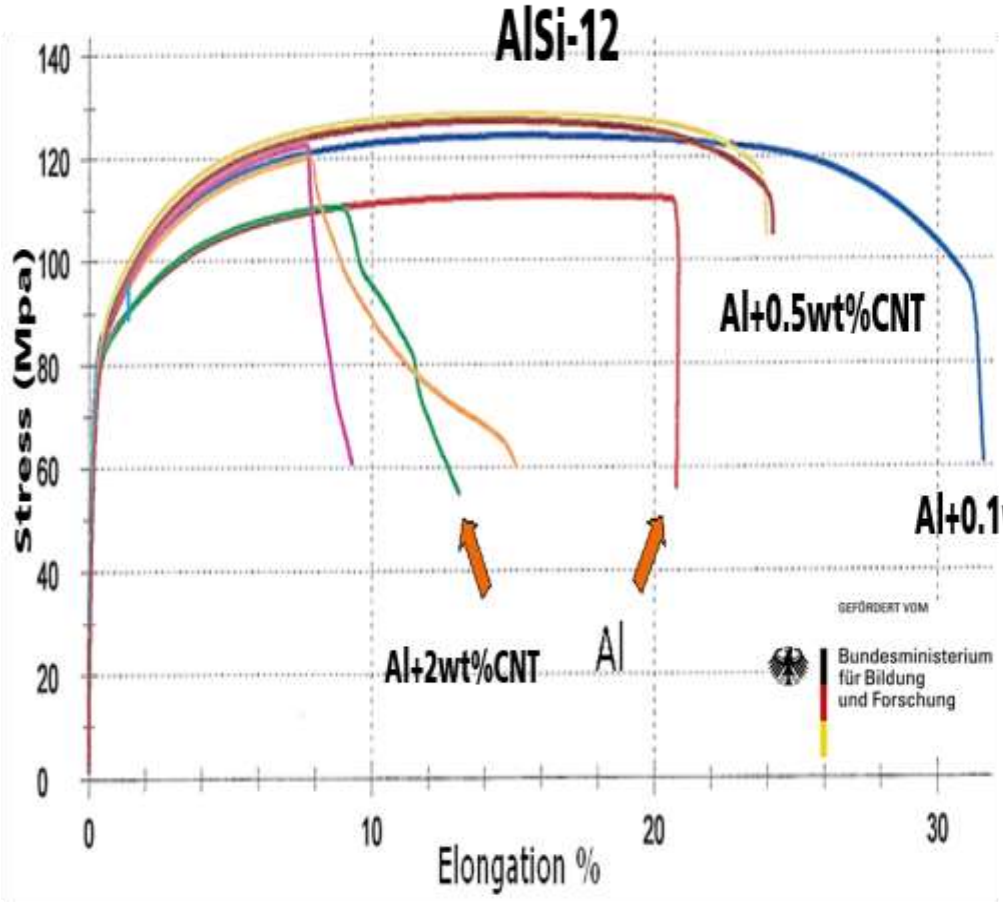
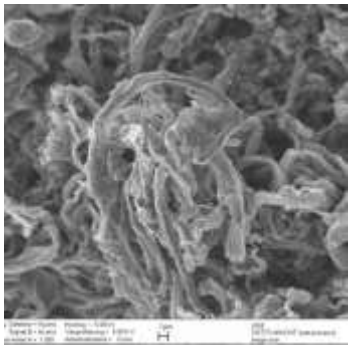
Nano Fiber reinforced Metal

CNT ALSi-12 Composite

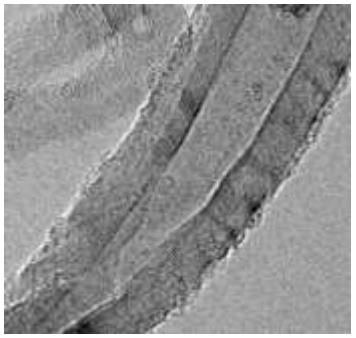


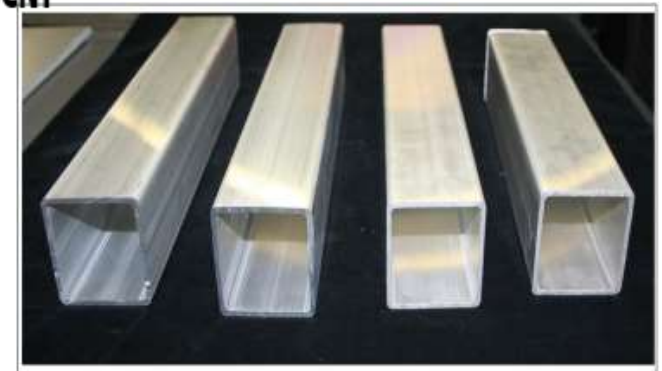
Source: Kolbenschmidt – Projekt Canamat

SEM Picture



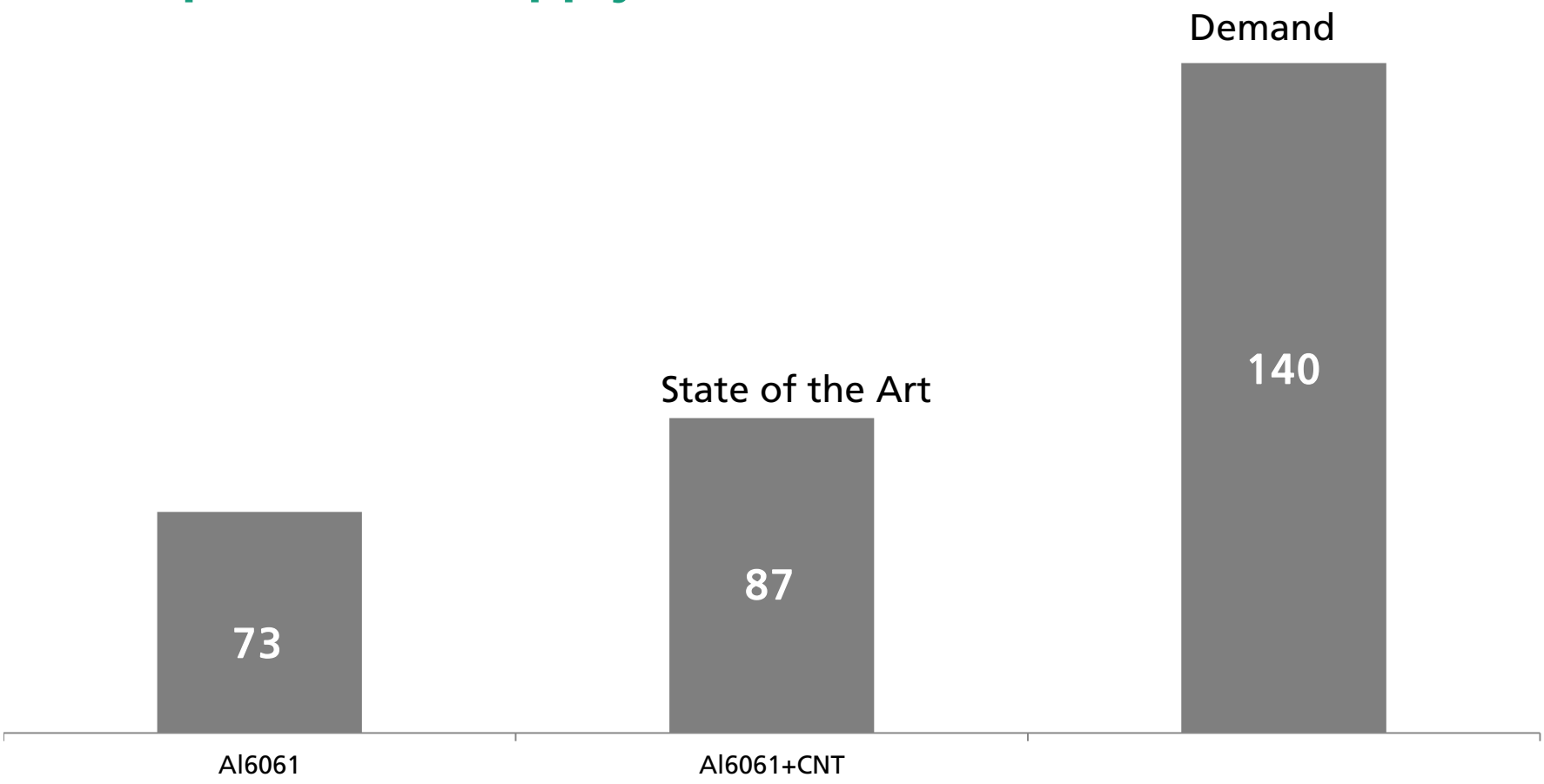
TEM Picture



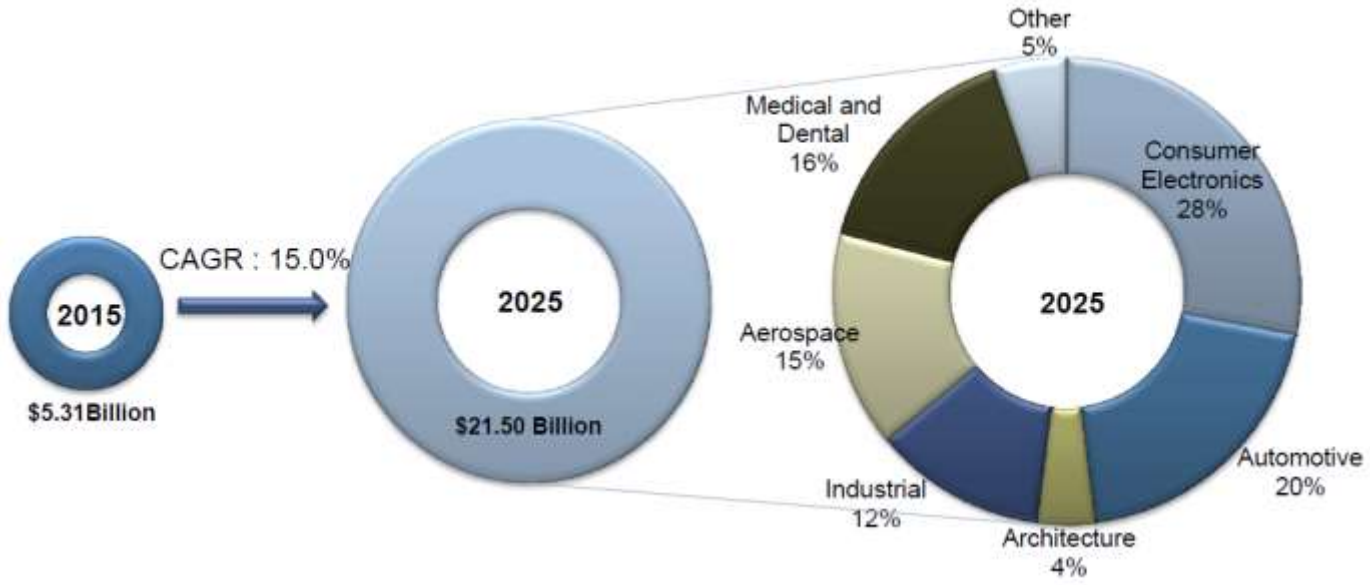


Nano Fiber reinforced Metal

Comparison of Supply and Demand



Additive Manufacturing
Market Forcast



Source Frost & sullivan

Additive Manufacturing
Lightweight design and construction

Used Materials

- Scalmalloy®
- Stainless Steel 1.4404
- Stainless Steel 1.4540
- Stainless Steel 1.4542
- Steel 1.2709
- Titanium Ti6Al4V
- Aluminum Alloy ALSi10Mg

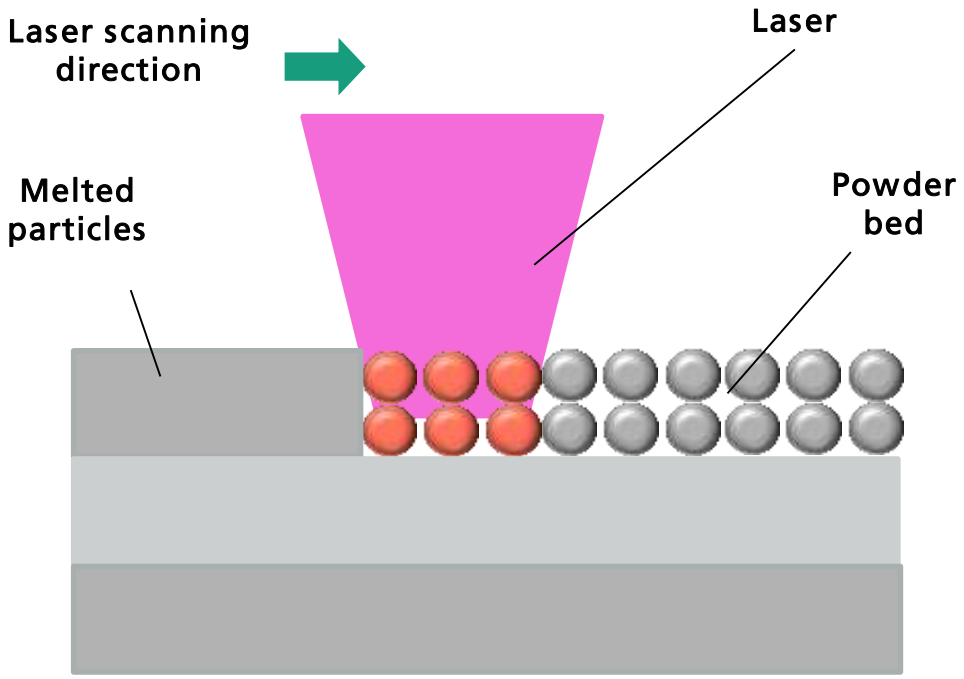
Source: AP Works

Additive Manufacturing
SLM Steering Knuckle

Source: Fraunhofer ILT

Material adaptation for additive manufacturing processes

Industrial challenge / problem setting



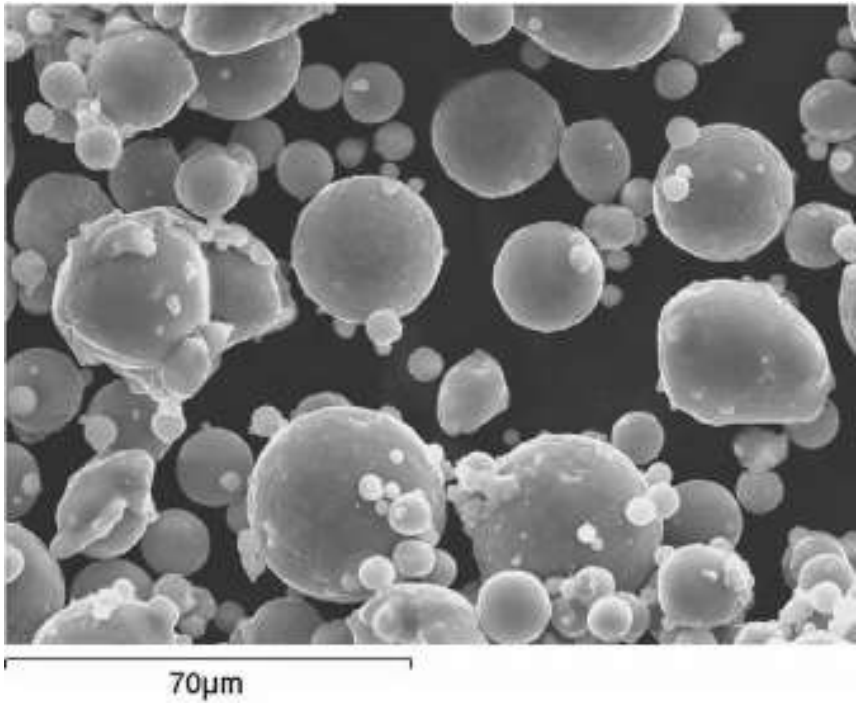
Ideal:
Homogeneous powder particles

Real:
Inhomogeneous powder particles

Homogeneous powder base for efficient additive manufacturing,
In titanium, for example, this homogenization is still the problem

Inhomogeneous geometry of metal powder

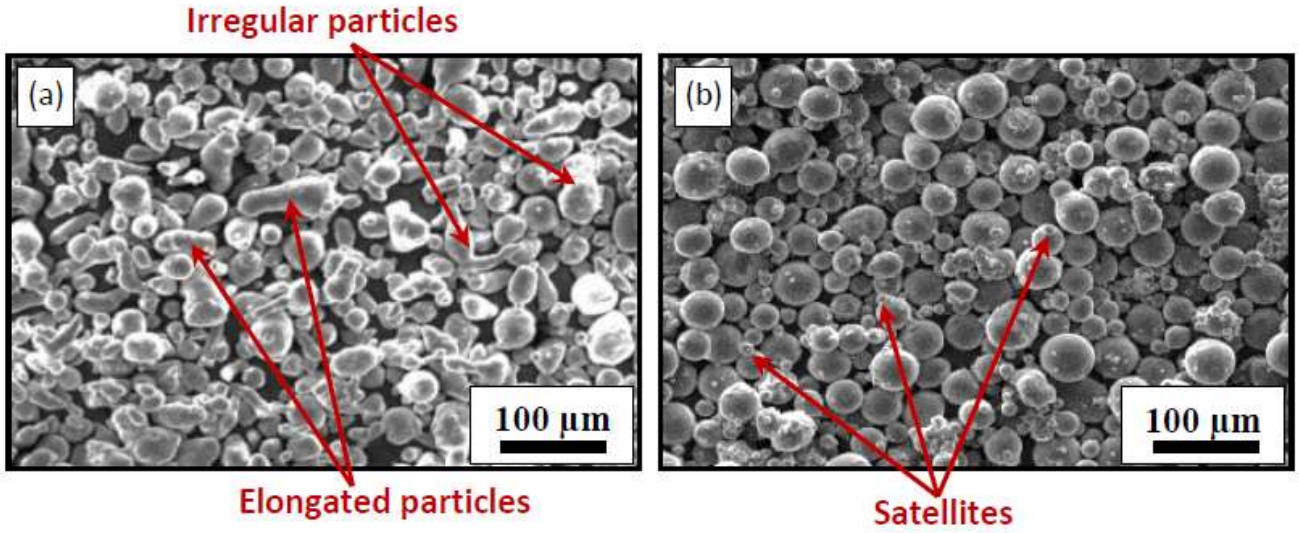
SEM Image AlSi10 Mg



Source: Yan , et. al. ; Materials Science and Engineering A 628 · March 2015

Inhomogeneous geometry of metal powder

SEM Image AlSi10 Mg



Source: Aboulkhair , et. al. ; Lasers in Manufacturing Conference 2015

Adaption of Materials for Additive Manufacturing

Industrial approaches to solution

1

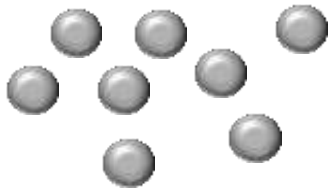
Inhomogeneous Powder Particles

RF-Plasma

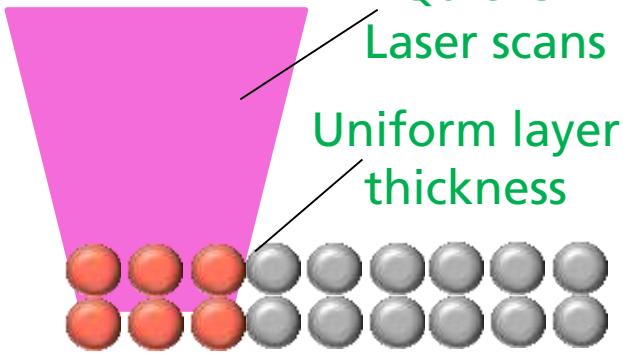
Homogenisation

2

Homogeneous Powder Particles



3



Homogenity of the powder particles refers to:

- Shape of particles
- Size or Particle Size Distribution
- Surface properties (Chemical Composition)

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RF Plasma Spheroidization
Main challenges / Productivity

Challenges

- Ex Schutz
- Automatization potential
- Handling and Manipulation
- Occupational safety
- Total running cost

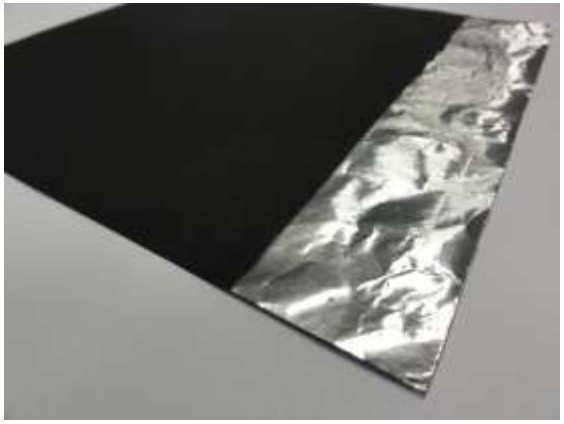
A short summery

- Devices and Parts will turn be „smart“
- Robot will collaborate with Robots, Tools and People
- Nano Materials will be increasingly used in lightweight design and new manufacturing methods

Reference Project : ElectroGraph

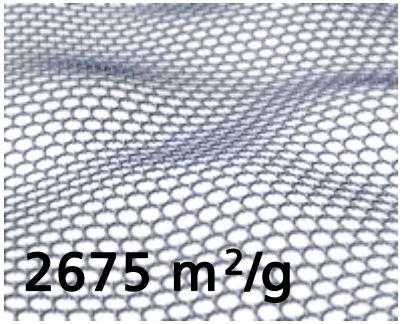
Graphene based electrodes for application in supercapacitors

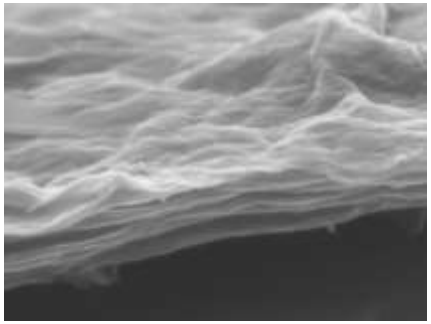
Development of materials and production technology for electrodes



Integration in a rear view mirror with PV module for energy self-sufficient mirror adjustment

High surface = high capacity





product development

Electrode

SuperCap

E-Auto

Demonstrator – Autonomous External Rear view mirror

Integrated graphene-based supercapacitor

and Photovoltaic Cells (PV) for Lancia Delta external rear-view mirror

FINAL GOAL

Cable removal by contactless remote control, solar cells and supercaps based power supplying.

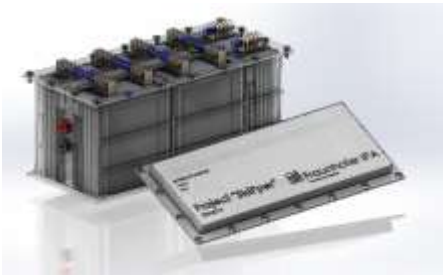
Project example:

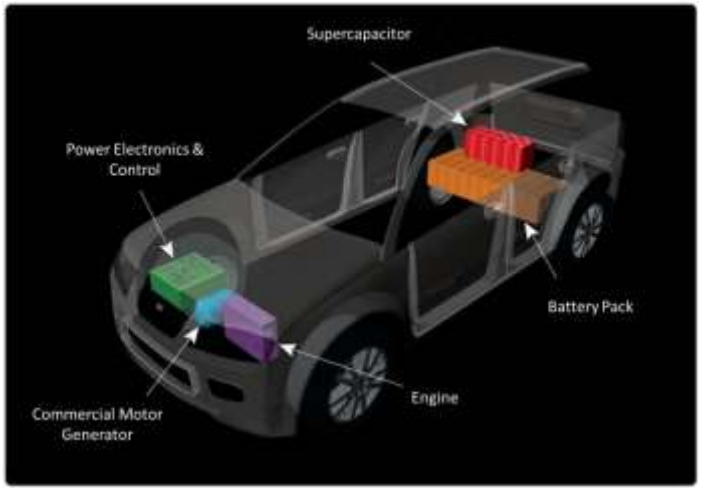
SkiPper - Supercapacitor as buffer system for storage of electric energy in automotive applications

Nanocarbon-based electrodes for electro mobility

- Buffer system for energy storage, compatible with long-time storage such as Li-batteries
- System integration, module development
- With AIST Kansai, National Institute of Advanced Industrial Science and Technology (AIST)

- Rapid-charging
- Long lifetime
- Power density superior to battery systems
- Vehicles for decentralized energy storage





Integration of supercapacitor in automotive application - here as support of battery pack

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Project example:
Power Industry – Storage Systems for Electric Power
FastStorage BW

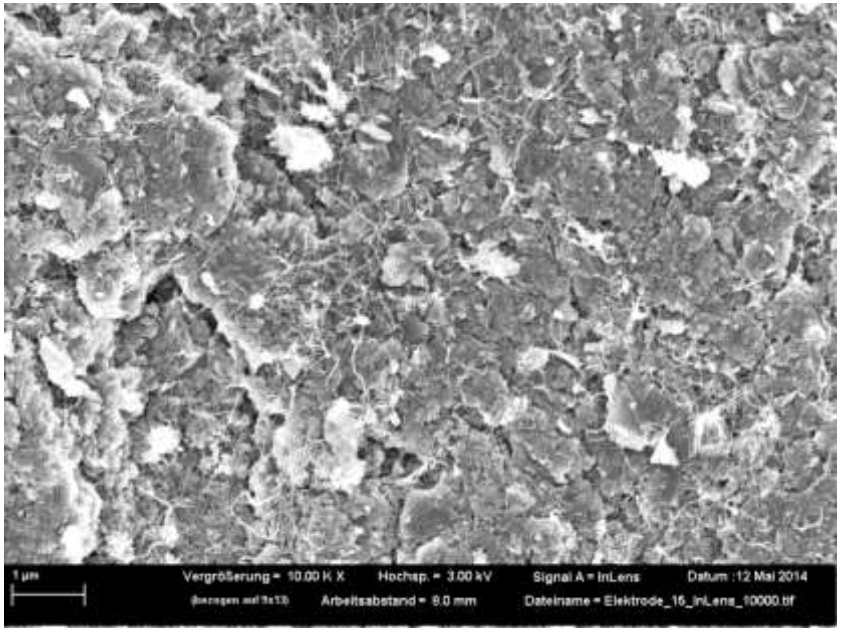
- **Task**
  - Development of novel high-performance and high-power storage cells (power caps) with a long service life and ultrafast charge, which is highly secure; development of the respective production processes
  - Defining application fields for energy recovery and efficiency increase in industry and e-mobility

- **Services provided by IPA**
  - New production methods for nanomaterial (graphene nanoplatelets) and electrodes with high potential for power storage
  - Development of a innovative, solvent-free dry coating method for better processing
  - Up-scaling wet chemical dispersion and application technology for a higher energy density

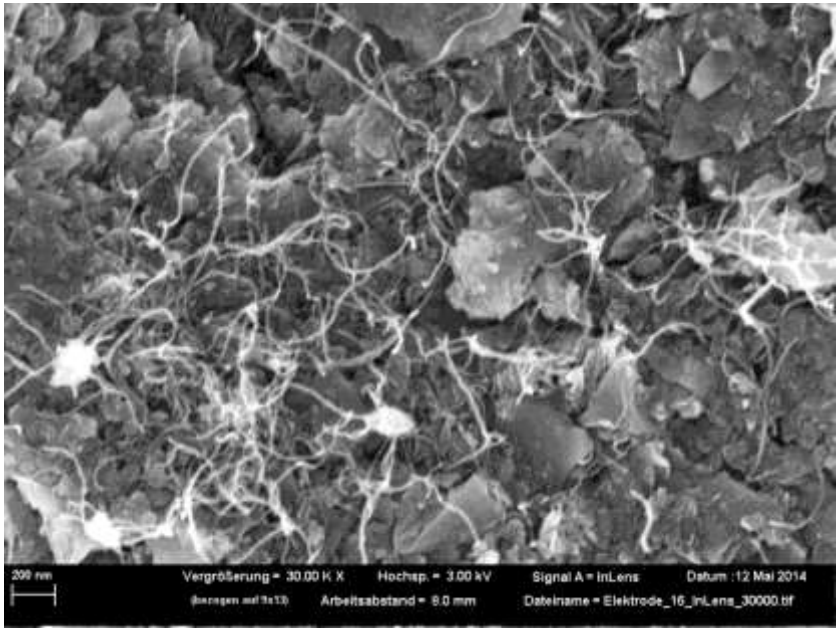
SEM of Composite Electrodes
Binder Substituion via Nano Carbons

Baden-Württemberg
MINISTERIUM FÜR FINANZEN UND WIRTSCHAFT

- CNTs replace the binder material
- CNT mesh keeps active material on electrode



(10.000 x magnification)



(30.000 x magnification)

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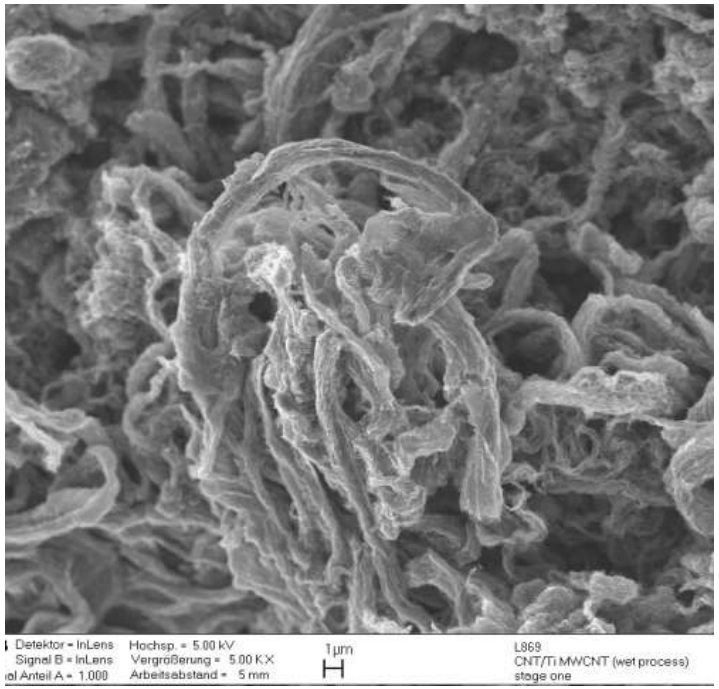
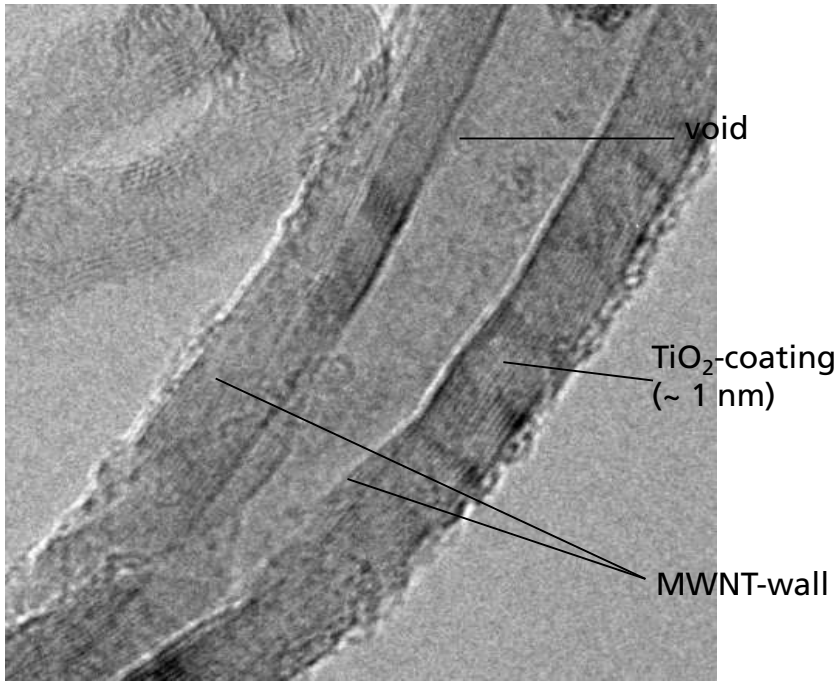
Synthesis and Functionalization
Hybrid Particles

TiO_2 coating of CNTs (Sol-gel procedure)

SEM



TEM



A short summery

- Devices and Parts will turn be „smart“
- Robot will collaborate with Robots, Tools and People
- Nano Materials will be increasingly used in lightweight design and new manufacturing methods
- Nano Materials and its fundamental understanding are a key enabler for energy storage systems

„Printed HMI“
The Need for Change – Advantages of Printed HMI

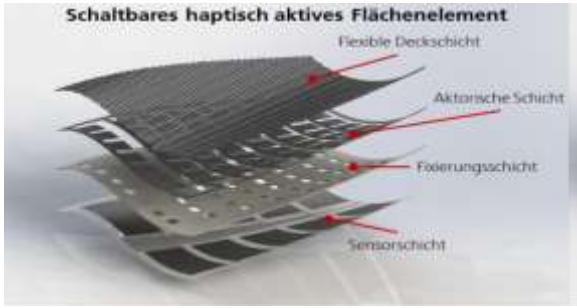
©BMW AG (background picture)

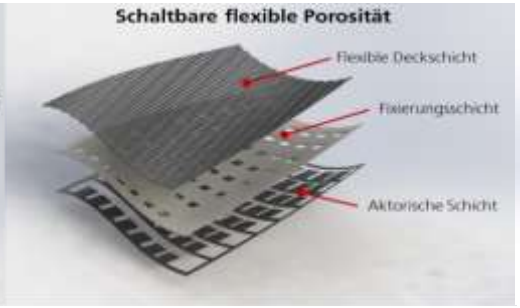
©DesignHMI

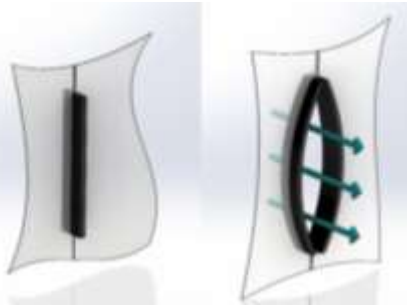
- **Advantages:**
  - Integration of sensor/actuator applications in curved, complex 3D surfaces
  - Personalized design & positioning of sensoric/actoric surfaces
  - Saving of material by selective sensor integration (compared to off-the-shelf components and according to desired degree of variation)
  - Better recyclability of printed HMI parts due to non-critical disposal of sensor-integrated polymeric parts (no rare metals etc…)
  - Reduction of metallic material use due to nanocarbon-based conductive inks/polymers. -> Better recycling and resource efficiency
  - Cost optimization due to simple & automated sensor integration/assembly.

Structured Active Surfaces

Printed Actuator Arrays for SFB1244 (Project Start in 2017)







- **Approach:**
  - Utilizing intrinsic action modes of electroactive polymer actuators (EAPs) for adaptive functionalities in buildings
  - Optimizing reliability and reproducibility by using uninterrupted manufacturing concepts e.g. roll-to-roll printing
- **Value proposition:**
  - Noise-free, continuous, intrinsic actuation of soft, flexible surfaces
  - Innovative manufacturing methods with printed structures for actuator fields

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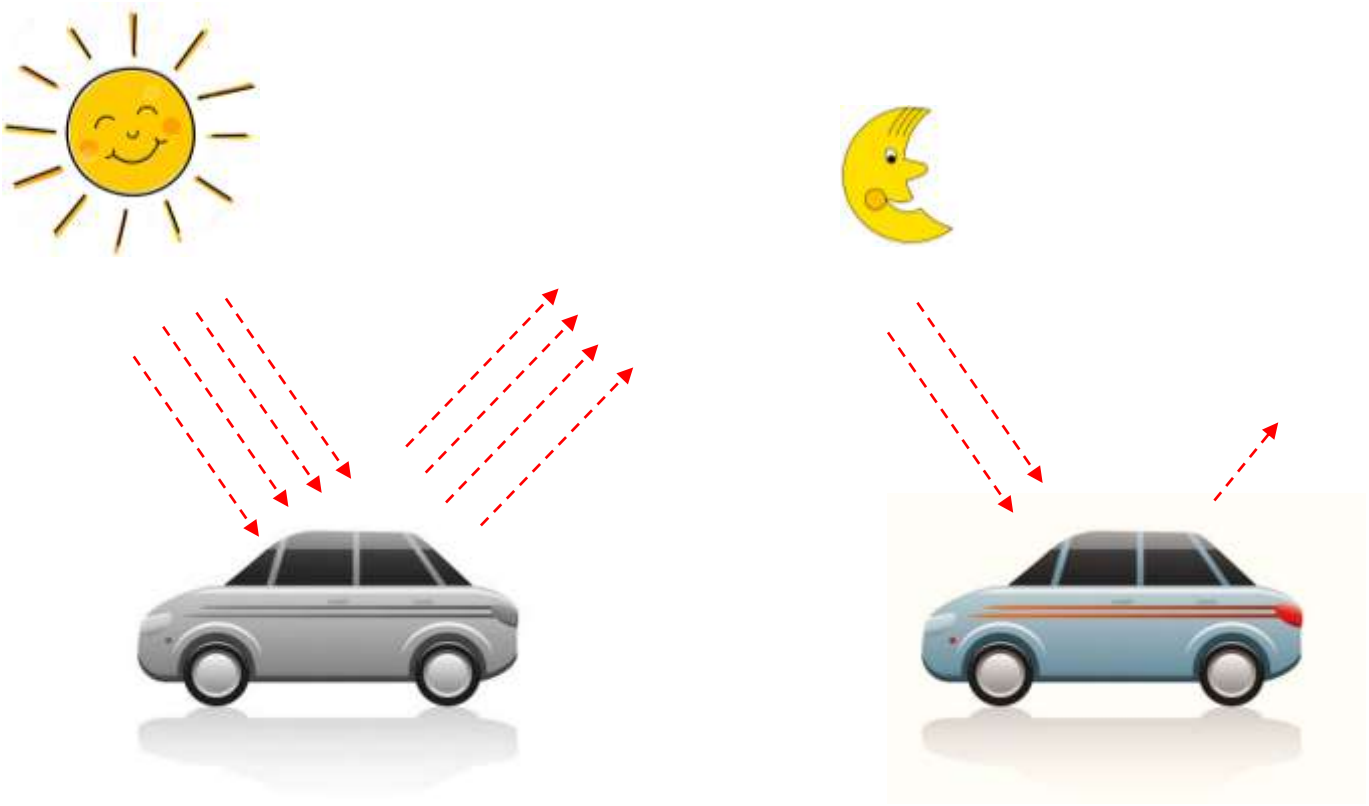
TRO INTER
PARTIMENT
I RIC

Smart Skins For Thermal Managment

Color Change Materials



SMART SURFACES
SMART SKIN

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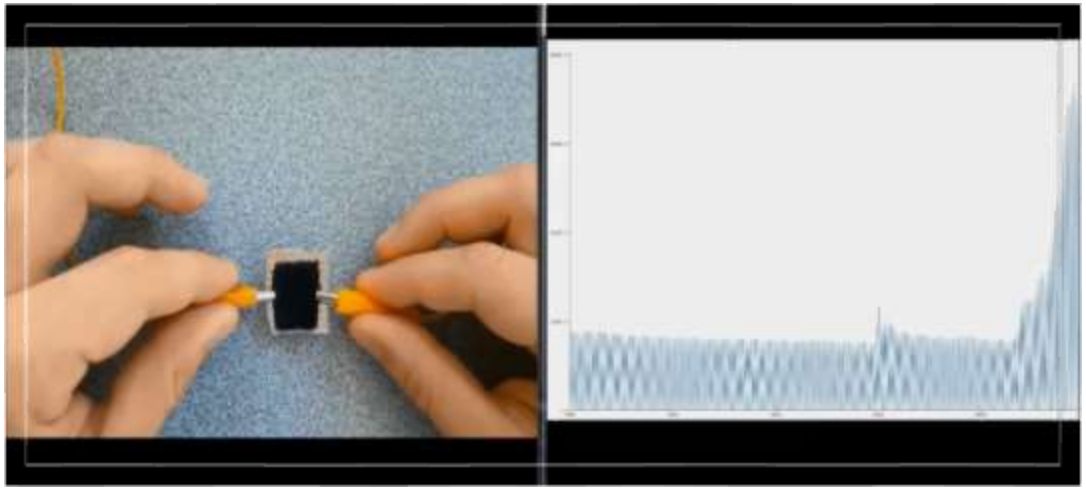
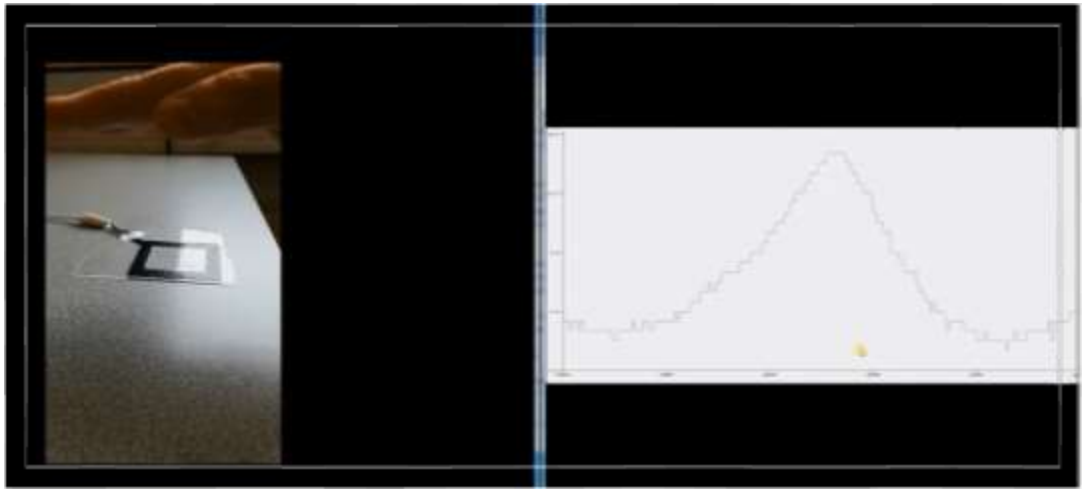
SMART SURFACES
SMART TEXTILES AND TIRES





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Final Conclusions

- Devices and Parts will turn be „smart“
- Robot will collaborate with Robots, Tools and People
- Nano Materials will be increasingly used in lightweight design and new manufacturing methods
- Nano Materials and its fundamental understanding are a key enabler for energy storage systems
- The car of the future will continuously communicate with its environment, passenger and supporting systems. This will lead t- significant increase in nano enhanced electronics

Visit us on

APPLIED SMART MATERIAL FOR AUTOMOTIVE

„FUNCTIONAL MATERIALS : DISRUPTIVE TECHNOLOGIES FOR CONNECTED CARS“

Stuttgart 8th November 2017

Thank you for your attention!

ご清聴ありがとうございました
Go seichō arigatō gozaimashita

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