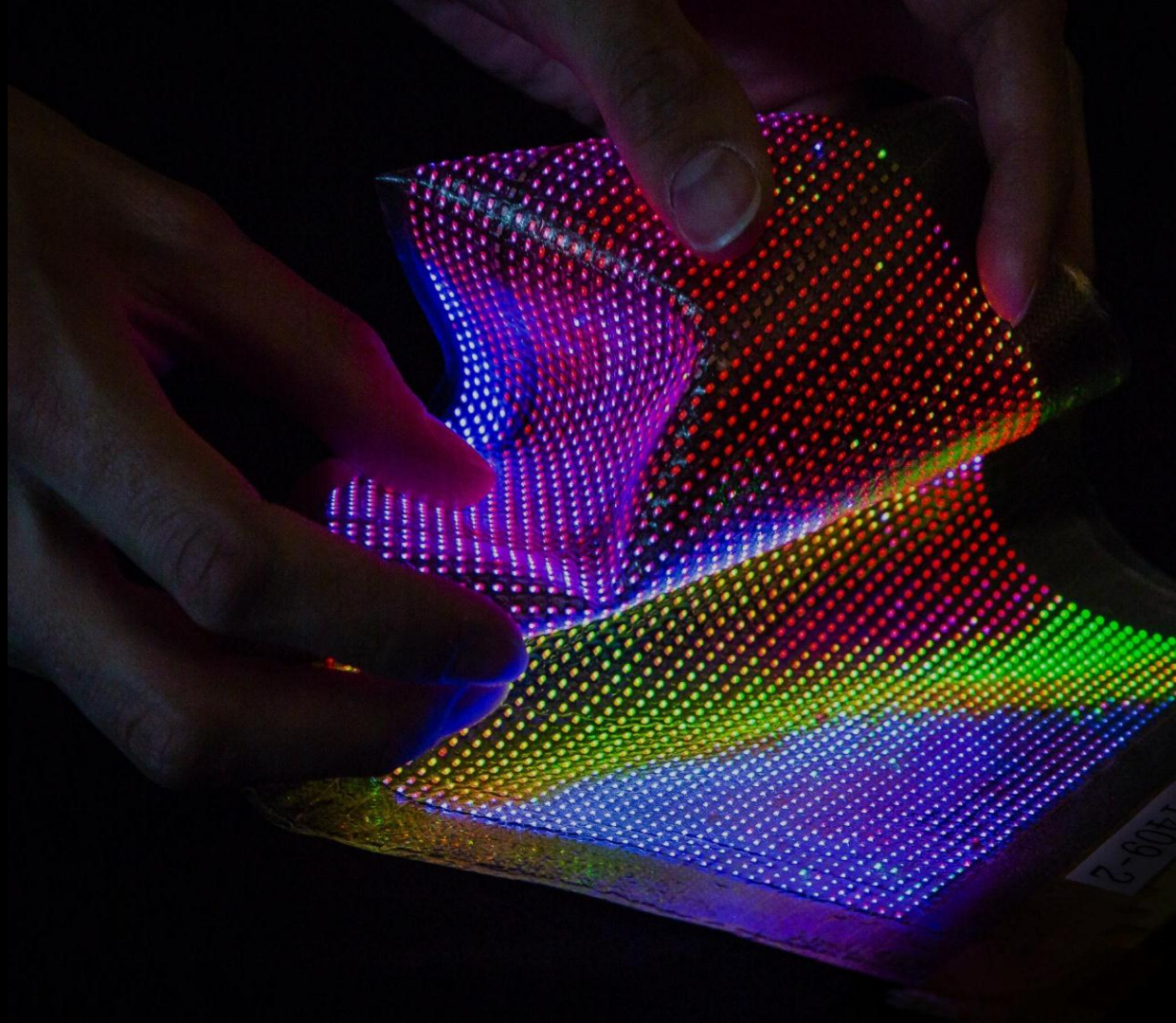
MOBILITY INDUSTRY INSIDER

DEEP DIVE

SMART MATERIALS

H2 2019



FutureBridge

WHAT'S NEW?

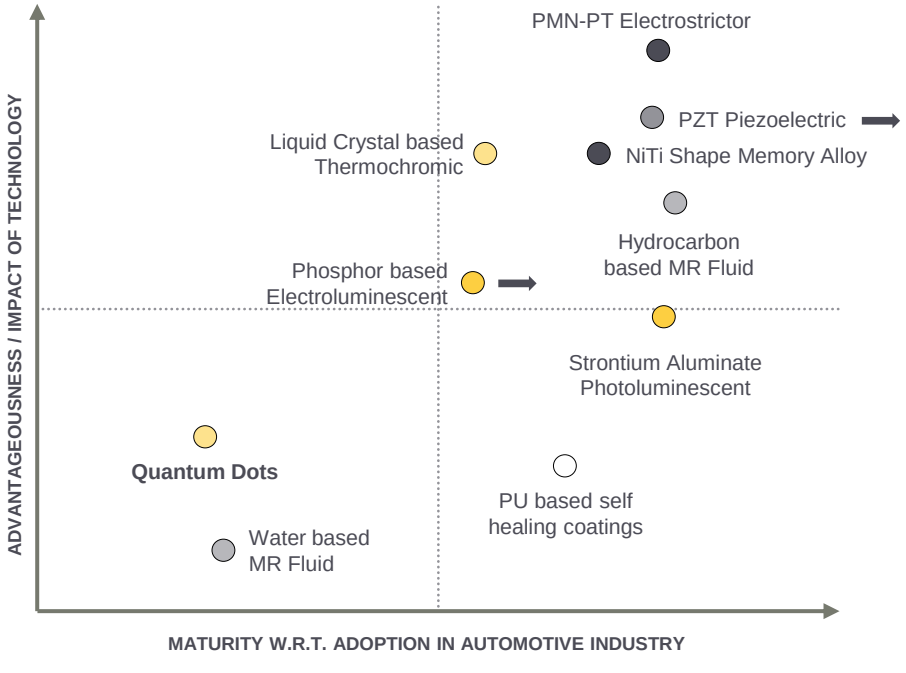
H2 2019

EXECUTIVE LENS

Summarized insights for Smart Materials w.r.t. trends in technology, market, and players

State of the Trend

Energy harvesting, passenger comfort and aesthetic features driving forward the adoption of smart materials



- Electro chromic, Thermo chromic materials are widely used for enhanced vehicles interior features, such as new head up displays, curved screens instead of dashboard etc.,
- Material and semiconductor companies are expanding their thermoelectric generator portfolio capitalizing on energy saving and fuel economy trends
- Smart glasses are finding new applications such as roof HUDs, thermal control in parked cars etc.

Electrochromic materials → Leading OEM's and Tier 1 suppliers are integrating electrochromic based smart glass technology into vehicles across the automotive sector.

Thermochromic materials → Automotive designers are replacing flat screens with conformable and shapeable OLCD/OLED displays .

Key Developments in past 6 months

- JLR's structural electronics research to allow curved screens to replace dashboard >>
- Covestro develops concept for car interior of the future >>
- Continental enhances Intelligent Glass Control >>
- BASF and Hymer develop camper van of the future with full diversity of material competence >>

Emerging trends

Color changing smart materials, photovoltaic materials, smart polymers and shape memory alloys are finding numerous applications in automotive sector

Carmakers deploy electrochromic glass with additional application

- Volvo is relocating electrochromic HUD to roof >>
- Rivian R1T truck and R1S SUV models are offering electrochromic glass roof styles >>
- Lamborghini's super sports car Sian launched with electrochromic roof >>

Read more in Q3 2019 Pulse - SM

Conformable and flexible display solutions for automotive applications

- FlexEnable announced that it has collaborated with Novares on the integration OLCDs into Nova car#2 >>
- Himax Technologies, Inc. launched its flexible OLED automotive display driver and timing controller for BOE Technology Group Co., Ltd. >>
- Visionox has demonstrated new OLED technologies at SID DisplayWeek >>

Read more in Q2 2019 Pulse - SM

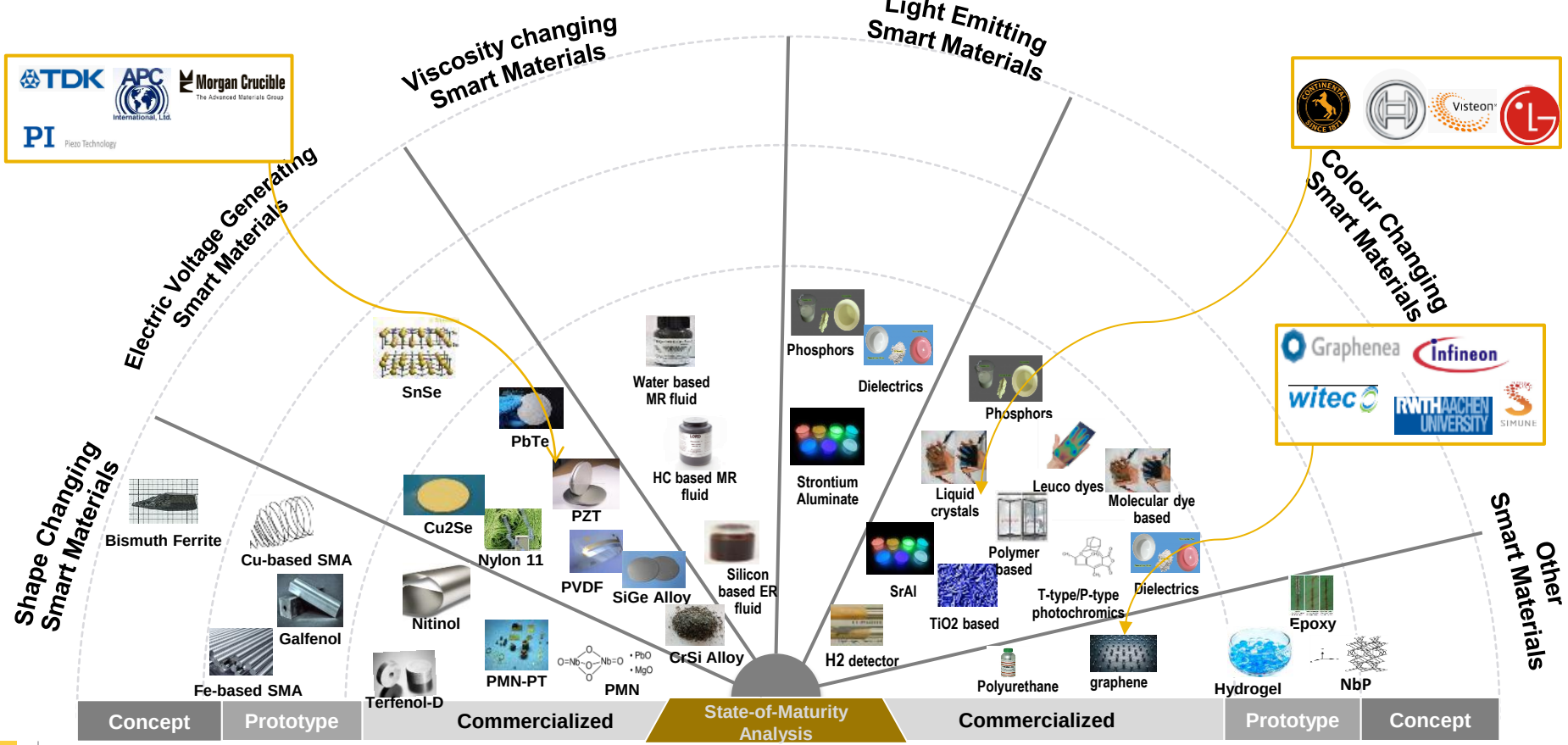
Researchers demonstrate effective thermoelectric materials

- Researchers from Beihang University have developed 10% selenium to tin sulfide tuned thermoelectric material >>
- Scientists from University of Texas and Texas Instruments Inc. TEG's based on nanostructured silicon thermopiles >>
- Researchers from North Carolina State University, and ORNL found that a paramagnetic material can be used as a thermoelectric material >>

Read more in Q3 2019 Pulse - SM

Maturity Fan Diagram

Although majority of the solutions are commercialized, and only few are on prototype/research phase



Impact of Megatrends

		Upcoming requirements	Opportunities for smart materials
Safety & Autonomy		• Increased passenger comfort, new seating configuration and dynamic positions, seat-integrated safety systems • Enhanced safety features to comply with regulations utilizing clever sensor integration • Increased communication with pedestrians	• Smart fabric in seats allows features to only be deployed when needed reducing screen or button need • Magneto rheological materials for damping in interiors • Integration of safety features in interiors and crash protection in exterior using shape memory alloys • Electroluminescent display features on exteriors
Electrification		• Vehicle to grid infrastructure • Improved battery thermal management solutions • Battery self diagnostics systems and inspection sensors	• Photovoltaic as source for charging stations or in vehicle roofs • Thermoelectric based energy recovery systems • Electrostrictive material in batteries to account for volume changes when charging/discharging • Use of graphene for EV applications
Connectivity		• Passenger monitoring on cloud • Increased number of display devices, HUDs • Sensors for driver health monitoring	• Piezoelectric material-based fatigue drive monitoring • Electro-chromic materials enhancing display devices by changing intensity based on surroundings

Impact of Megatrends

		Upcoming requirements	Opportunities for smart materials
Shared mobility		• comfortable seats and blunt edges are needed since the interior space is being largely utilitarian. • Reduce wear and tear of tires due to continuous usage • Autonomous ride sharing services	• Thermoelectric fabrics on seats , anti-bacterial coatings and OLED/LCD displays • Nitinol based shape memory alloy is on testing phase to reduce wear and tear of vehicle tires • Photochromic tinting on windows to maintain inside cabin temperature in order to make it comfortable when passengers enter the vehicle.
	Reduction in weight	• Electrification and autonomy will increase the demand for weight reduction in vehicles.	• Adoption of light weight , high performance polymers, advanced composites, and aluminum and lightweight steel alloys. e.g.: Polycarbonate films in future automotive cockpits • Graphene / graphene composite based car body panels

Front Running Technologies – Adoption & Industry development

Electrochromic and thermochromic materials gaining momentum, high industrial and research activity observed in second vector of 2019

Thermochromic Material - OLED/LCD displays

Audi AI:ME OLED display

Byton's screenfilled cockpit

FlexEnable's OLCD display for Nova car#2

Himax launched OLED display for BOE

Kia unveiled concept car with array of 21 smartphone-sized LCD on dashboard

Sharp launched foldable OLED displays for cars

Read more in Q2 Pulse SM

Key Research Activities

- Self-supported liquid crystal film for flexible display and photonic applications >>
- Compact large size colour 3D dynamic holographic display using liquid crystal display panel >>

Photovoltaic Material – car roof top

Fisker Ocean SUV with solar roof

Lightyear One fitted with solar roof

Sion EV with solar roof

Toyota Prius hybrid with solar roof

Kia-Hyundai testing on solar roofed cars

Read more in Q2 Pulse SM

Key Research Activities

- Flat, spectrum splitting concentrator photovoltaic system for electric vehicle roof >>
- Photovoltaic powered ventilation system for parked electric car >>

Front Running Technologies – Adoption & Industry development

Color changing materials such as electro chromic and thermo chromic are finding more applications in modern car interior design.

Color changing material – Smart glass

Rear view mirror into an HD video screen

Developing smart windows for cars

Electronically dimmable window

Enhancing Intelligent Glass technology

Windshield-projected Active Driving Display

Read more in July 2019 Bulletin SM

Key Research Activities

- Reversible Ag electroplating onto ITO electrode for smart window >>
- HSNs/VO2 bilayer coatings with optimized optical performances and mechanical robustness for smart windows. >>

Electrochromic Material – colour changing roofs

Volvo's patent on electrochromic HUD

McLaren 720S Spider with optional electrochromic roof

Lamborghini Sian with electrochromic roof

Rivian R1T truck and R1S SUV models with electrochromic glass

Uniti One electric car featuring electrochromic roof

Read more in Q3 Pulse SM

Key Research Activities

- Electrochromic metallo-supramolecular polymers showing visible and near-infrared light transmittance modulation >>
- Electrochromic tungsten oxide thin films deposited by e-beam evaporation for smart windows >>

New Inline Products: Flexible/curved displays

The car interior has evolved significantly over the years, but the most exciting changes are still to come. Flexible and curved displays bring outstanding opportunities for automotive interior.

Flexible display

- Displays need to conform naturally to the curved surfaces of the car and be unobtrusive when not displaying information. Often they will need to be non-rectangular as well as non-flat.
- Recently suppliers have introduced flexible displays which made of flexible materials such as OLED, OLCD that are ultra thin, light weight and can be conformed and cut into different shapes and sizes .

Products

FlexEnable's flexible display
- Flexible OLCD display
- Flexible OLED display

Continental's curved AMOLED display

Bosch's curved instrument cluster

Main suppliers :-

FlexEnable BOSCH Continental

Advantages and applications

Displays for increased safety : 'invisible' pillar concept

>> >>

Displays for increased safety : Side mirror replacement using curved OLCD

NOVARES >>

Displays for infotainment : shaped infotainment display concept

Displays for infotainment : S-shaped centre unit consisting of twin 12.1" OLCDs

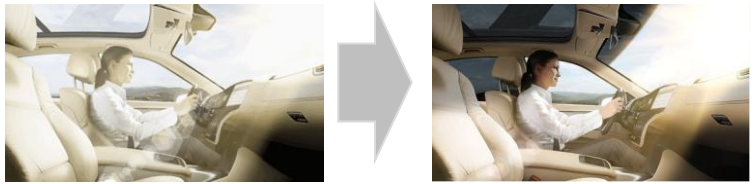
NOVARES >>

New Inline Products: Smart glass

Leading OEM's and Tier 1 suppliers are integrating smart glass technology into vehicles across the automotive sector through a system based approach.

Technology

Automotive grade smart glass windows with SPD and LC technology will provide instant shading and solar reflection in all windows eliminates road glare and mitigates interior temperatures



Products

Continental's Intelligent glass control

Gauzy's smart glass with liquid crystal and SPD technology

Main suppliers :-

Continental | Gauzy | Research Frontiers SmartGlass.com

Implemented models

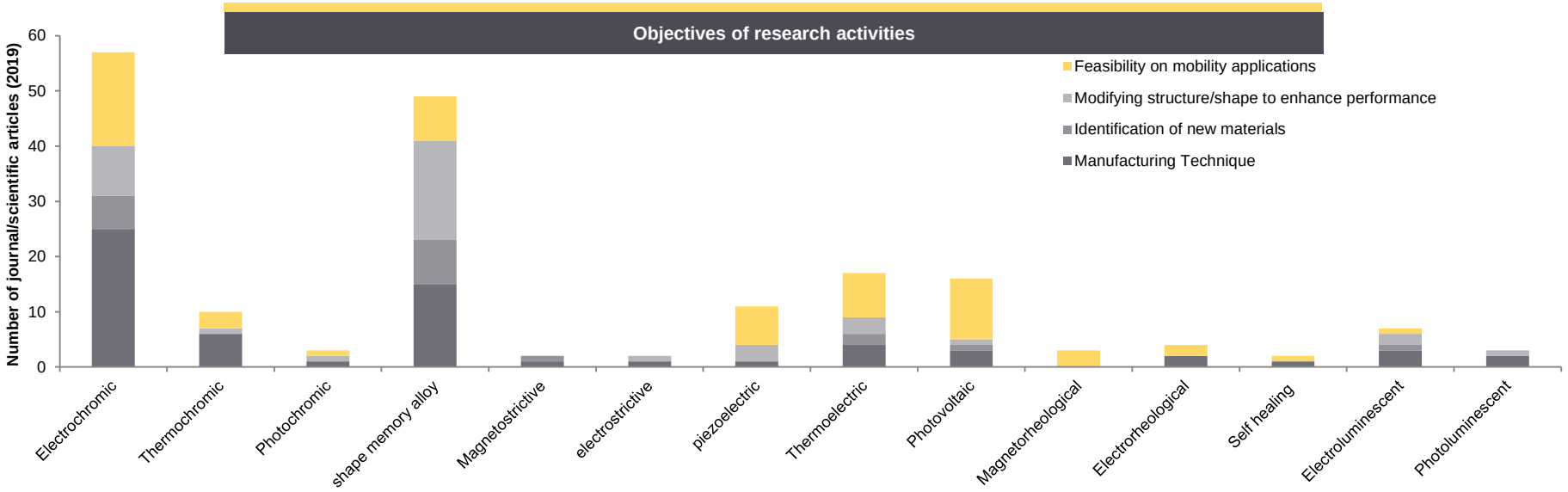
Daimler Gauzy partnership made first-ever Dark RetroFit LC film for the automotive industry

Mercedes S-Class models utilizes SPD sunroofs to switch the transparency

McLaren's electrochromic sunroof with SPD technology

Research Focus Areas

Light emitting and color changing smart materials are at the forefront of research for seeking new applications while researchers are also focusing on new manufacturing techniques for shape memory alloy.



- New materials & manufacturing techniques are being researched for electro chromic materials for display systems in vehicles.
- Electrochromic and shape memory alloys are being explored for aesthetic features, in both vehicle interior and exterior

For additional information please refer to Appendix of H2 2019 Deep Dive

IP Activity Scenario – Major OEMs & Tier 1 Players

Piezoelectric and light emitting are the most focused smart materials in present market.

Major Player vs Application use cases

- Valeo is leading in IP filing of smart materials with focus on display, illumination, and window
- Major OEMS have done patent and research activity in the area of display module and suspension system in past six months
- Less activity seen in panels, headlamps, seats in past six months

	Display module	Exhaust Energy Recovery	Exterior Illumination	Exterior Panels	Headlamp	Interior Illumination	Interior Panels	Seats	Suspension	Window	Total
Ford	3	2	1	1				11	6	2	11
GM	6								6	1	13
Valeo	19		4	3	3	2				1	26
BMW		2			8				1		3
Honda	3		1		6	3			6	1	13
JLR	2	4		1			1		4	5	6
Toyota	7	1			7				1	1	9
Continental	4	1							1	2	8
Hyundai	4	3			5				3	2	12
Faurecia	2										2

Major Player vs Smart material usage

- Many research and patenting activity for piezoelectric material are done by Major OEMs in seating and suspension system
- Ford has done tremendous utilization of smart materials in automotive application
- Jaguar came up with smart material based novelty in past six months

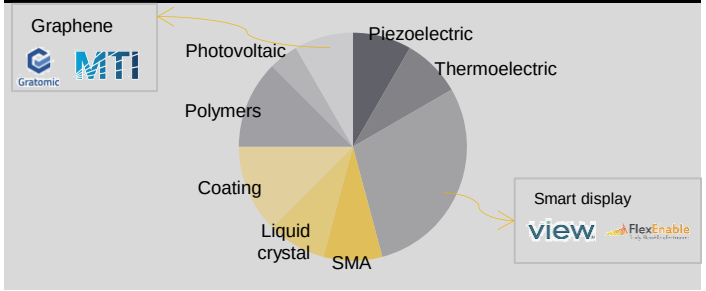
	Electro-chromic	Electro-luminescent	Electro-rheological	Magneto-rheological	Photo-luminescent	Photo-voltaic	Piezo-electric	Shape memory alloy	Thermo-chromic	Photo chromic	Total
Ford	2	3	1	3	56	6	15	8			93
GM	2			1		1	12	11			27
Valeo	6	48			3	1	21	8			87
BMW	1		1	1		2	5	6			16
Honda	1	7		2	5	1	2	1			19
JLR	1	4		3			4	1			13
Toyota						8	9	8			25
Continental	1					1	12	2	1	1	18
Hyundai	1	3		2		1	3	4			14
Faurecia	2	1					12	6			21

Above representation is based on relevant IP published in last 6 months; for additional information please refer to Appendix of H2 2019 Deep Dive

Startup Activity Summary

Startups captured throughout 2019 contains more number of startups in colour changing smart materials

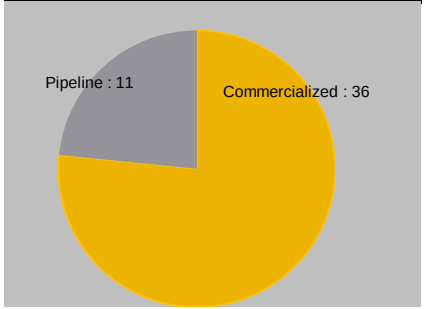
Startups in SM by technology



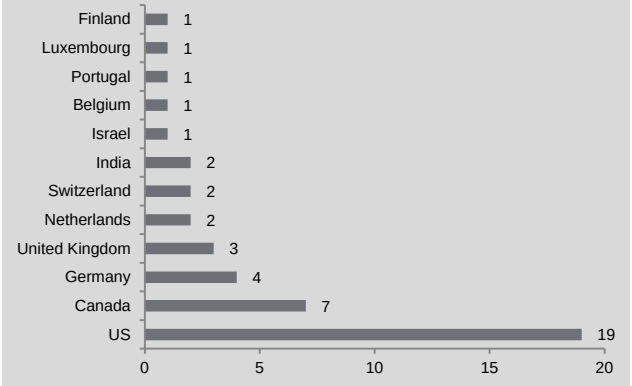
Some key startups active in Q3 2019

- FlexEnable (Truly flexible electronics) → Flexible OLCD/OLED displays
- SONO MOTORS → Solar powered electric cars
- TACTOTEK (SMART MOLDED STRUCTURES) → Surface materials, piezoelectric sensors

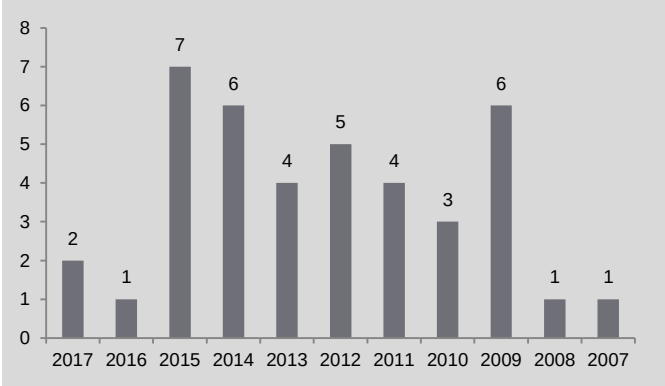
Startups by state of maturity of products



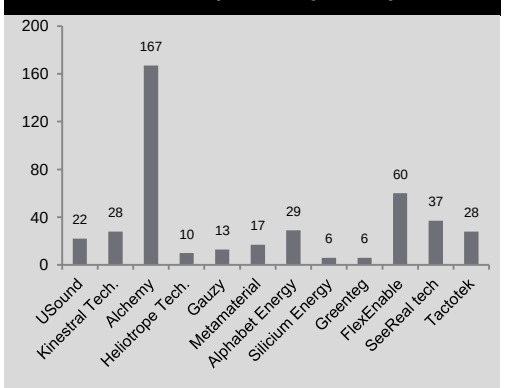
Startups by geography



Startup incorporation

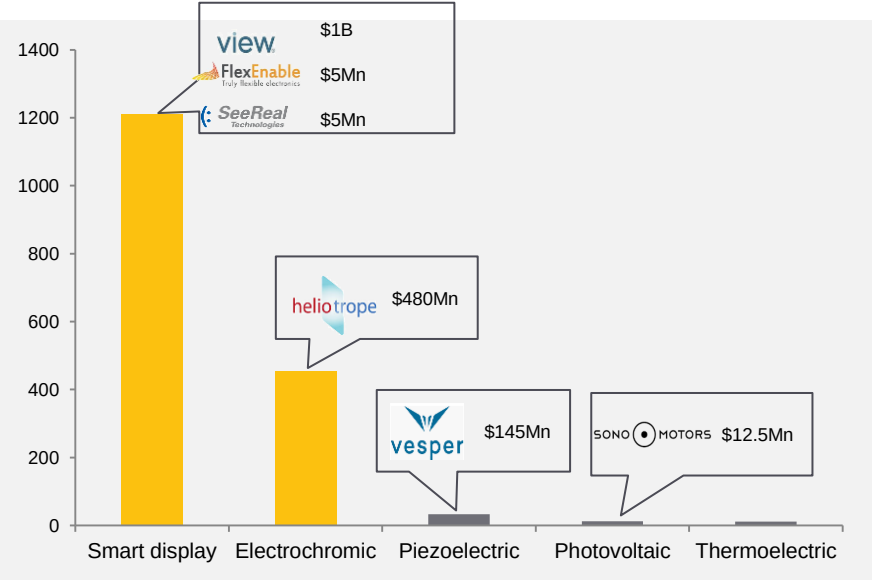


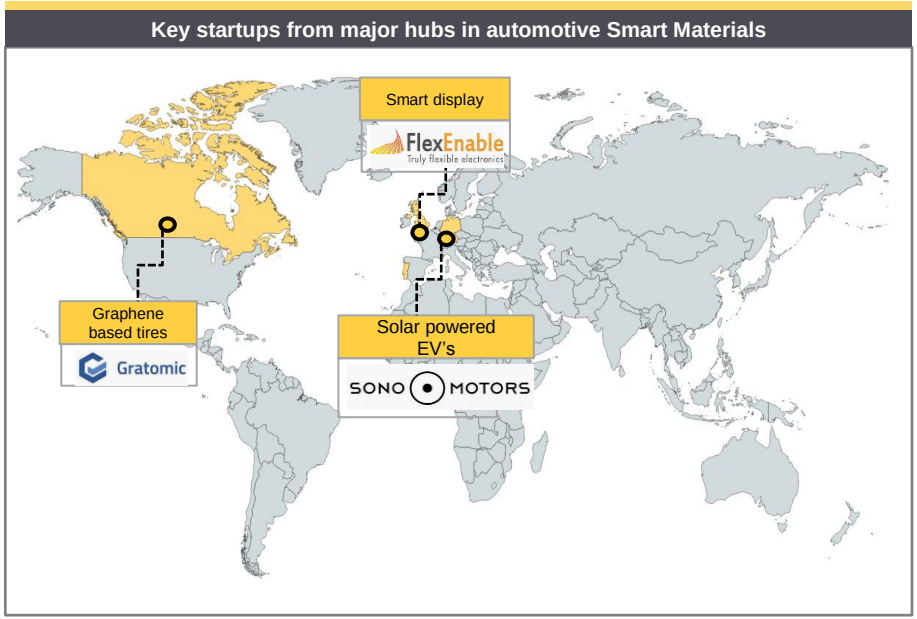
Number of patents by startup



Funding distribution & activities

More investment secured by players in smart displays and smart glass in 2019





- View, Inc. got 1.1 Billion funding for its Smart Protect technology in which glass surface is added with sensors.
- FlexEnable secured 5 Million funding for its bezel-less flexible OLCD displays, which is a breakthrough inventions in smart materials.
- SeeReal technology received 5 Million funding for their liquid crystal based H3D display solutions.
- Startups which work on new material for smart displays, electrochromic and piezoelectric materials got more funding in this quarter.

Exteriors Applications

Increased adoption of smart materials in dampers and energy recovery; innovative uses in bumper help enhance safety

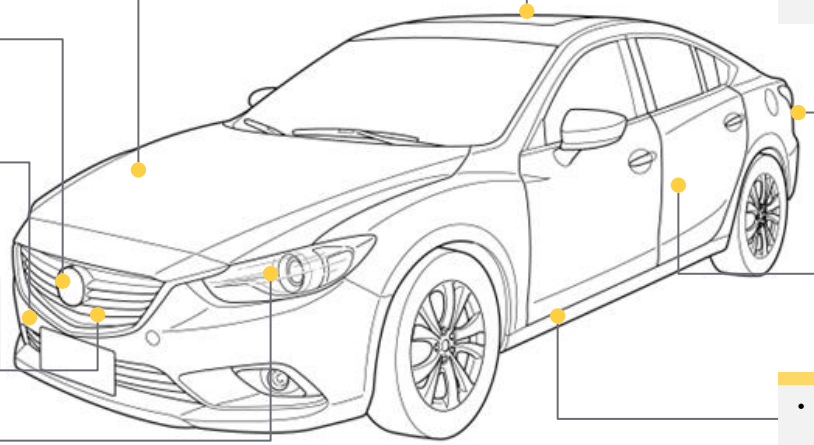
- **Shape Memory Alloy**
  Controlled vibration to reduce aerodynamic drag

- **Electroluminescent**
  Illuminated vehicle emblem

- **Shape Memory Alloy**
  Smart bumpers

- **Thermoelectric**
  Radiator heat exchanger

- **Shape Memory Alloy**
  Headlamp vibrations damping



- **Electro chromic Material**
  Vehicle Sunroofs

- **Photovoltaic Material**
  Solar panel sunroofs

- **Thermoelectric**
  1. Exhaust energy recovery
  2. EV battery Cooling

- **Self healing material**
  1. Coatings/paints
  2. Paints for easy detection

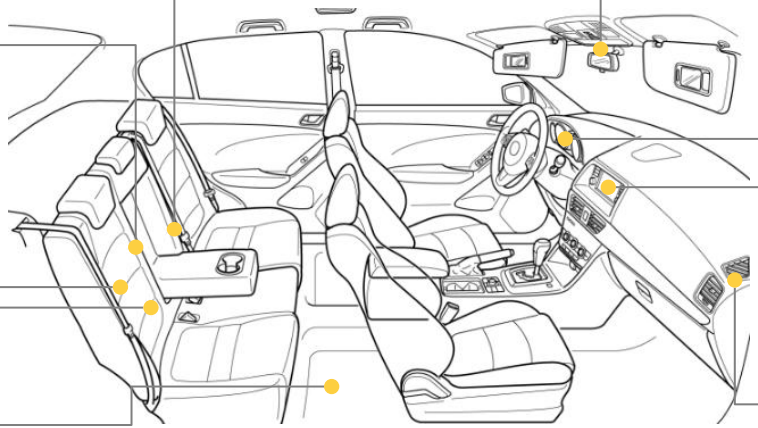
- **Magnetorheologic fluid**
  Dampers

- Thermoelectric heat exchanger in radiator & exhaust, photovoltaic sunroof make vehicle adept in energy harvesting capabilities
- Shape memory alloys enable dynamic projection on the exterior surface to reduce drag
- Electrochromic sunroof and electroluminescent emblem add aesthetic features to exteriors

Interior Applications

Ability to get miniaturized enabling smart material to penetrate in seats; electroluminescent and Electrochromic materials enhance user experience

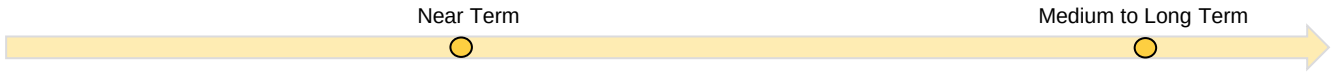
- **Shape Memory Alloy**
  Variable support in seat
- **Shape Memory Alloy**
  Massage systems in seat
- **Electrostrictive**
  Lumbar support
- **Thermoelectric**
  Heating/cooling vehicle seat
- **Electroluminescent**
  Interior panel surface light



- **Electro chromic Material**
  Rearview mirrors
- **Electro luminescent**
  Instrument clusters
- **Electrochromic**
  Display panels, HUDs
- **Electrostrictive**
  Lumbar support

- With the ability to form miniaturized components, smart materials are enabling safety and comfort features integrated in the seats
- Electroluminescent features add aesthetics features to the interior which could unlock further vehicle personalization
- Display panels and mirrors adopting Electrochromic materials to enhance view according to ambient light

Future Outlook



Technology		
Viscosity Changing Fluids	• Use cases of magneto-rheological and electro-rheological fluids in damping and vibration control apparatus in suspension and exteriors	• Adopting active collision protection systems for controlling stiffness of exterior support structures
Color Changing Materials	• Flexible OLED/OLCD displays • Thermochromic material to help indicate temperature of components • Photochromic window tinting for passenger comfort	• Ultrathin, foldable, customized and low cost flexible displays • Interior light intensity control • Curved OLED screens on dashboard
Shape Changing Materials	• Shape memory alloy enabling smart comfort features in the interiors and vibration control • Magnetostrictive sensors in drivetrain	• Features such as smart bumper, protective shield system using SMA • Accounting volume change in battery
Voltage Generating Materials	• Energy recovery systems using thermoelectric generators (heat energy) and piezoelectric (vibrations energy)	• Smart interior sensing capabilities and comfort features using piezo and thermo-electrics

Things to watch out for!

- Players are exploring solar roof cars for sustainable mobility. Fisker introduced world's first full length solar roof electric SUV. Toyota and Hyundai are also working on it.
- Automotive designers are replacing dashboards with conformable and shapeable OLCD/OLED screens. JLR developing curved OLED on dashboard
- OEM's and suppliers are focusing on smart glass applications in vehicle interiors. Continental is enhancing its Intelligent Glass Control technology so that windows can be integrated more effectively with the car's user interface.

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