“***Electronics Evolution: Empowering Innovation through Advanced Materials Integration***”

IPC welcomes the European Commission’s focus and attention to the needs of the electronics industry with regard to Advanced Materials. We concur that electronics is a sector in which Advanced materials are critical for performance, quality, and innovation throughout the value chain. Indeed, given the interlinks between the industries within the value chain a comprehensive analysis of the challenges, drivers and opportunities is much welcomed.

Indeed, materials for electronics use are a matter of constant research, development, and innovation which is triggered by the need of:

- higher power on smaller spaces
- heat dissipation and cooling due to power losses
- higher frequencies, signal integrity and electromagnetic interference
- advanced packaging and heterogeneous integration
- functional plastics and plastronics
- additive technologies
- optical and quantum materials.

Access, development and qualification of materials for the electronics value chain is central to the competitiveness of the European Union given the key enabling role of electronics for Europe’s Industries and their twin transition. Electrification and Digitalization are developing rapidly, while sustainability is an essential driver for the entire electronics industry. Key success factors include advanced material development, innovation, performance and availability.

Many different segments need to be considered using a ‘Silicon to Systems’ approach. Materials research, development, sustainability, quality assessment, and long term reliability performance all must be considered for electronic materials selection. Areas include:

- Semiconductors
- Electronic packaging – new and legacy
- HDI printed circuit boards (PCBs)
- Printed circuit board assembly (PCBA)
- Final system assembly (FSA)

Materials usage assessment is needed spanning all of the above areas including to respond to evolving legislative requirements (e.g. PFAS proposed Restriction).

Product and Technology Roadmaps are commonly used by different Industries to pinpoint and prioritize the need for advanced materials. The drivers include,

- Strategic: Identification of a competitive advantage
- Product: Customer performance or technology requirement
- Manufacturing / Quality: Need for operational improvement
- Environmental: Compliance requirement

Two challenges that exist are material release readiness from the supplier and material compatibility. Industries requiring high reliability, like Automotive and Aerospace, generally require that a material be fully developed prior to implementation into a product design validation. Thus, the material qualification must be performed "proactively" based on the Product and Technology Roadmaps. Ideally, the material supplier should already have their production process qualified in time for the OEM's design validation build. Most suppliers are reluctant to incur the expense of production process qualification in advance of having a committed purchase order. This can slow the entire adoption process for a new material.

Depending on the Industry impacted, substitution of critical raw materials may require re-qualifications that are costly and could take six months or longer, e.g., Automotive, Health Care. Substitution can also impact the electronics manufacturing process if one assembly line is used for multiple customers and all customers must approve the change for the change to take effect. It's a "market push" challenge. Automotive, for example, generally has a materials life cycle that is closely aligned with a product life cycle. Any changes must fit within the product life cycle framework. Once the product design and process validations are completed, it becomes very difficult to make substitutions or changes. New materials nearing market readiness having market potential will benefit from the "market pull" effect where customers are more eager to realize the technology advantage or cost benefit.

By way of background, to illustrate the range of requirements and drivers for the electronics industry we highlight the following areas:

High performance and high frequency Electronics

Silicon based semiconductor chips are developing rapidly to fulfil the performance demands of next generation electronics especially in HPC, consumer, defence, infrastructure, internet of things IOT, and autonomous mobility electronics. The performance development of silicon chips by scaling in the sense of Moore's Law is coming to an end and requires novel ways called advanced packaging and heterogeneous integration.

In addition, antennas in package (AIP) to shorten RF paths need highly advanced materials development. This field is growing rapidly on a global scale and requires the development of a large number of very advanced materials. Two examples shown below:

- **IC substrates**, e.g. ultra-low loss materials (glass core), laminates, organic interposers with dielectric constant lower than silicon, build-up films, resins, coatings, surface finishes
- **Hybrid bonding** materials for interconnections, increased bandwidth, heightened power efficiency, and reduced parasitic signals and thermal resistance due to the absence of underfill.

Once the semiconductors are packaged, they are assembled together with a number of other components to printed circuit boards (PCBs). The requirements for PCBs are rapidly increasing and massive development of base materials is needed to cover the ever increasing demands for performance and frequencies. There is almost no production of PCB laminates in Europe which is contradicting the strategy of independence for critical materials. Despite of that there are major development needs in the area of ultra-stable materials for microvia stacking and stable in-plane CTE for reduced mismatch to assembled components. There is a need to consider flexible PCB materials. Requirements are getting tougher for high frequency applications such as copper roughness, uniform reinforcement, and ultra clean materials for resistance to electrochemical migration.

To assemble printed circuit boards with semiconductor packages and other components, auxiliary materials that meet the higher demands of those advanced electronics are essential:

- fluxes,
- solder pastes,
- underfills, edge and corner bond,
- coatings,
- adhesives and thermal interface materials TIM,
- encapsulants and potting compounds

need to be developed further to meet the demands.

To secure the sensitive electronics against environmental conditions, final system assembly takes place. The bare electronic assembly needs to be encapsulated into housings. New material development is required for e.g. functional high-performance plastics which enable EMI shielding and thermal properties and enable the replacement of e.g. metal housings to reduce weight leading to a smaller carbon footprint. New lighter and more cost efficient metal housings, as well as bezels and insulators are needed.

5G devices require low-loss materials e.g., thermoset materials for reduction in the Dk and Df, Polytetrafluoroethylene (PTFE) for high-frequency applications such as automotive radar systems, high speed/high frequency (HS/HF) circuit boards and connectors, liquid crystal polymers (LCP) for smartphone antennas, low temperature co-fired ceramic (LTCC) for compact high frequency filters.

6G devices require reconfigurable intelligent surfaces (RIS) that can manipulate the phase, amplitude, and polarization of impinging electromagnetic waves. Those RF applications require proper shielding on different levels of the electronic assembly to avoid electromagnetic interferences EMI. Many innovations are ongoing, naming a few: Solution processable conductors for package level shielding, particle-free inks metallized made in-situ that produce smooth coatings and eliminate the risk of nozzle clogging, metamaterials produced in periodic structures for frequency dependent EMI shielding, MXenes - a class of materials made up of metal carbides or metal nitrides that have excellent conductivity and are lightweight.

Power Electronics

Electrification in many areas, predominantly e-Mobility from scooters to VTOLs, solar and wind energy, leads to increased demands and further development of power electronics.

Silicon IGBTs will be replaced successively by SiC MOSFETs and GaN devices. The form factor of those high power semiconductor chips will shrink in order to reduce cost. This leads to more efficient cooling requirements enabled by advanced solder and sinter materials (e.g. Nano Ag-sintering and Cu-sintering materials for die and substrate attachment) to assemble those chips to high performance ceramic or metal insulator substrates, e.g. AlN, Al_2O_3, Si_3N_4 substrates. Bond wires to connect the power semiconductor with different conductors in the circuit need to carry higher powers which requires adaptions to other materials and form factors, i.e. Al to Cu, wires to ribbons.

Novel Electronics: Plastronics, Additive Electronics, Optical and Quantum Materials

Electronics are found everywhere and new ways of design materials and technologies are always being developed. A few of them, that are rapidly developing in Europe, are requiring advanced material development.

Very high advanced electronics are combining different physics areas in one product. So called Complex Integrated Systems (CIS) are developing rapidly and require high standards for materials and technologies. Electronics are combined with optics, photonics, and mechanics. In addition to the above mentioned critical materials, light weight, precise and functional optical materials such as lenses, wave guides, and optical interposers are needed.

Plastronics and in-mould electronics require conductive inks, e.g. copper inks, dielectric inks, and electrically conductive adhesives and need to survive the forming and molding steps of the functional plastic material that involve elevated temperatures, pressure, and elongation. Advanced materials are needed to serve a number of new technologies which are in development, e.g. selectively functional surfaces.

Additive manufacturing enables one-of-a-kind production and significant waste reduction. There are diverse developments ongoing: from additive processes in production lines up to fully printed electronics. Insulating, printable and temperature resistant resins and granules as well as conductive inks and interconnections need to be developed.

Quantum materials are an emerging field, both in condensed matter and organic semiconductors e.g. quantum dots in sensor applications.

Recommendations:

- A silicon-to-systems approach taken for electronic materials assessment is necessary. This spans semiconductors through electronic packaging interconnected to printed circuit boards into final system assemblies.
- Further road mapping of electronic materials is needed.
- Quality, performance and reliability of advanced materials selection should be balanced with availability, resiliency, design for sustainability, recyclability and circularity.

About IPC

IPC is the global association that helps OEMs, EMS, PCB manufacturers and suppliers build electronics better. IPC is dedicated to furthering the competitive excellence of its approximately 3,200 member companies, including the more than 600 in Europe. They represent all facets of the electronics industry, including design, printed board manufacturing, electronics assembly, and testing. While the membership includes many multinational companies, the majority are small and medium sized enterprises.

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