Polymer-based nanocomposites in semiconductor packaging

Prepared By-

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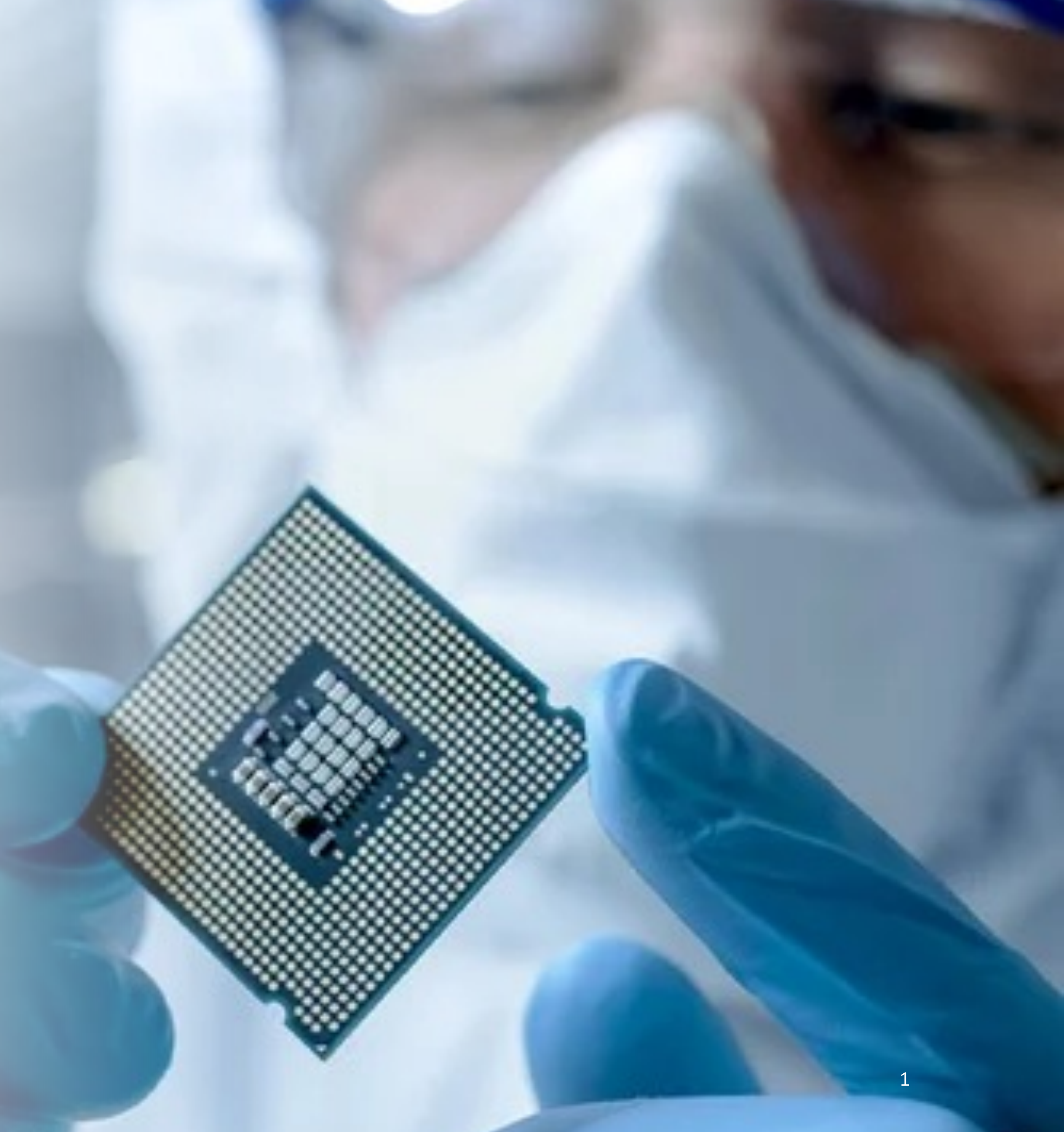
Abstract

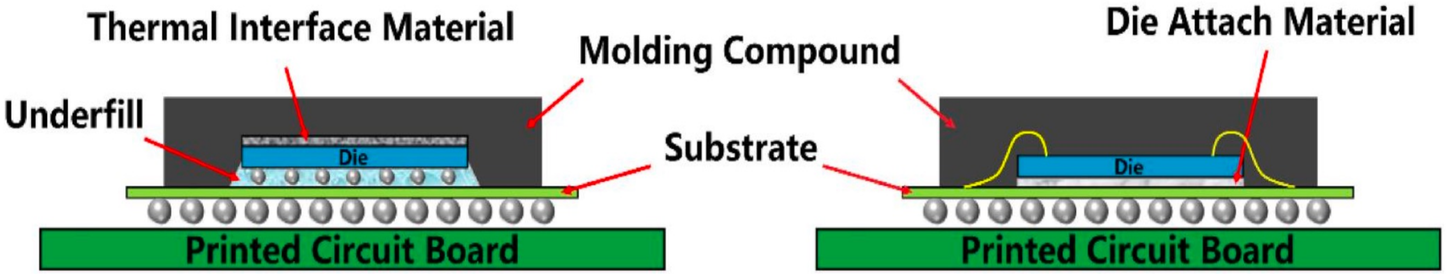
- **Role of Semiconductor Packaging Materials:**
  - Provide reliable protection and support and provides the electrical connection between the chip and the external circuit.
- **Advantages of Polymer-Based Nanocomposites:**
  - Low cost, easy processability.
  - Tunable properties.
- **Critical Properties Required in Semiconductor Packaging Materials:**
  - Low dielectric constant and dielectric loss.
  - High glass transition temperature.
  - Fast thermal conductivity.
  - Suitable coefficient of thermal expansion.
  - Low viscosity and good processability.
- **Effective Approaches for Enhancement:**
  - Modulation of the polymer matrix.
  - Introduction of suitable fillers.
  - Modification of the filler surface.



Introduction

➢ **Evolution and development of Semiconductor Devices and Packaging Materials :**
- Shift towards miniaturization, light weight, high power, and high density. Adoption of 5G/6G network technologies.
- Transition from metal-based and ceramic-based materials to polymer-based materials.

➢ **Critical Roles of Packaging in Chips:**
- **Physical Protection:**
  - Isolation of chips from the external environment to prevent corrosion and Protection against external stimuli ensuring safety in all aspects.
- **Electrical Connection:**
  - Achieved through wire bonding or flip chip technology.
  - Optimization of wiring length and impedance ratios for correct signal waveform and transmission speed.
- **Standard Specification:**
  - Packaging with standard size, shape, number of pins, pitch, etc.
  - Matching with printed circuit boards (PCB) for standardization and convenience in production.



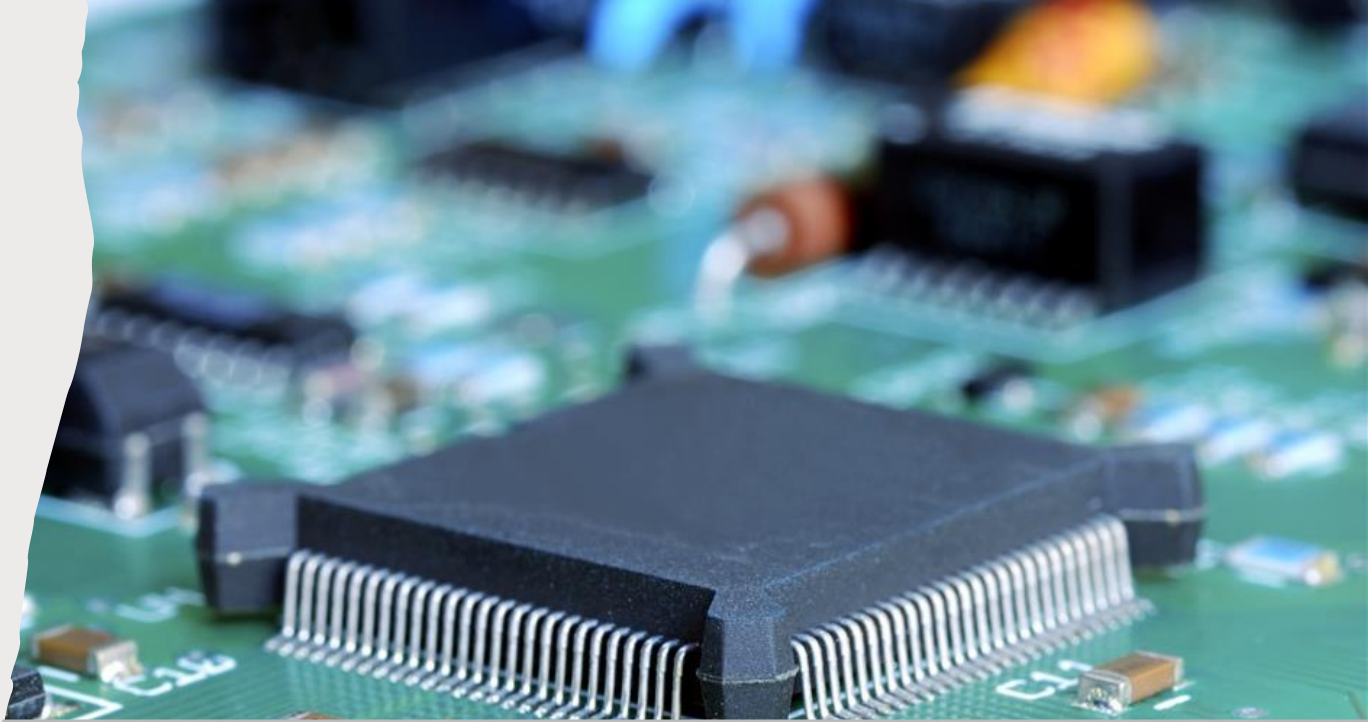
1. Wan, Y.-J., et al.: Recent advances in polymer-based electronic packaging materials. Compos. Commun. 19, 154–167 (2020). https://doi.org/10. 1016/j.coco.2020.03.011

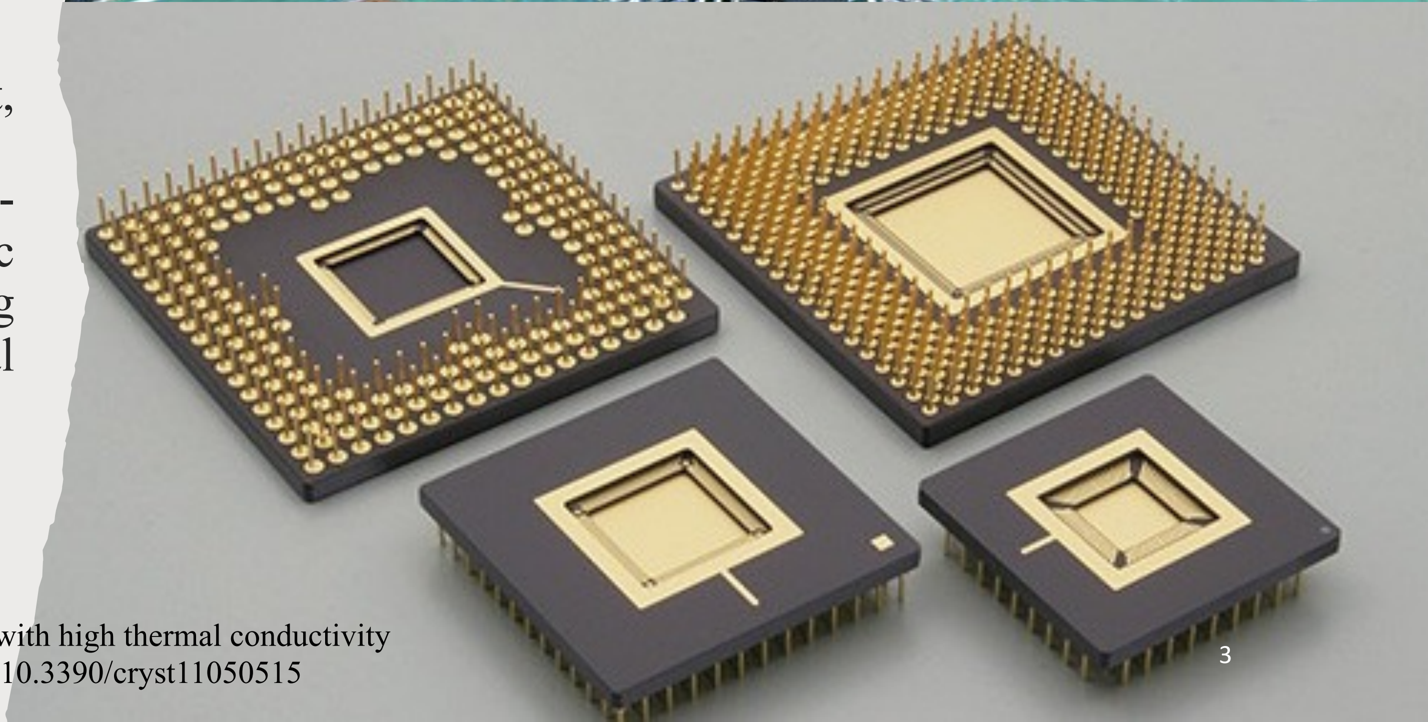
Types of Packaging Materials:

- **Metal-Based:**
  - Early use due to high thermal conductivity, mechanical strength.
  - Disadvantages- mismatched CTE, high density, and high cost.
- **Ceramic-Based:**
  - Good high-frequency performance, excellent insulation, high reliability, and thermal stability.
  - Disadvantages- Complex and costly process.

Both metal and ceramic based is suitable for aerospace and military engineering.

- **Polymer-Based:**
  - Dominant choice for miniaturized, lightweight, and low-cost semiconductor products.
  - Criteria for good polymer-based materials- high thermal conductivity, low dielectric constant, high-frequency stability, matching CTE with chips, sufficient mechanical properties, low mass density.

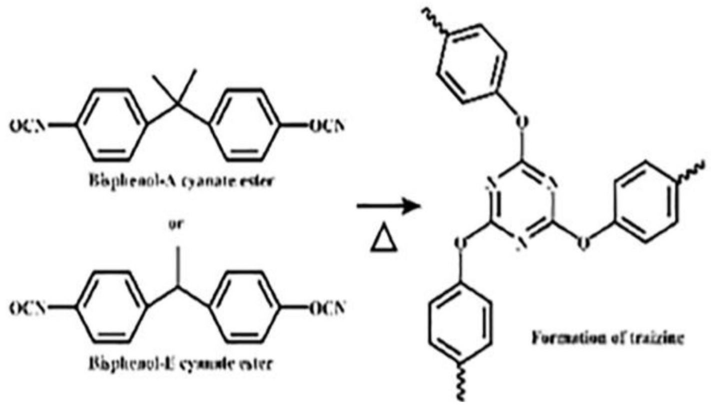


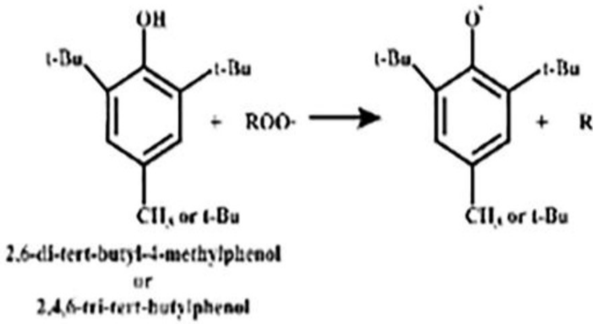


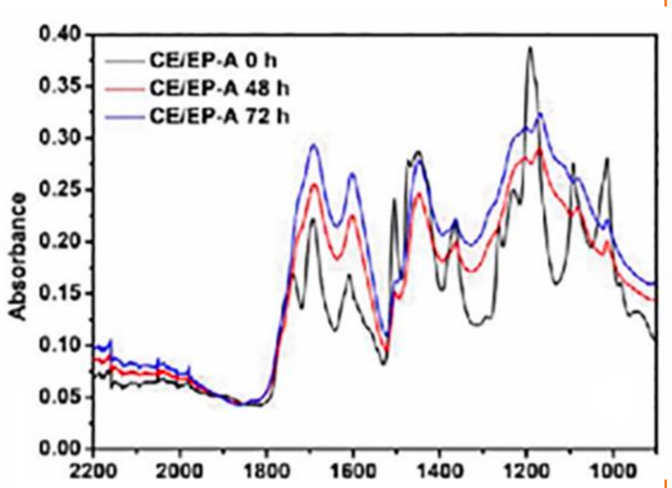
2. Chen, M.Q., et al.: The preparation of high-volume fraction SiC/Al composites with high thermal conductivity by vacuum pressure infiltra-tion. Crystals 11(5), 515 (2021). https://doi.org/10.3390/cryst11050515

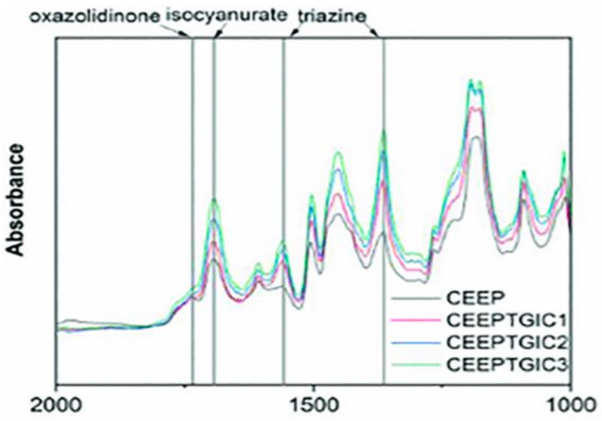
Polymer based Nanocomposite Application
1) Moulding Compound

- Epoxy (EP) resins are widely used due to their high adhesive strength, low shrinkage and heat resistance.
- Epoxy moulding compound (EMC) typically consists of 70%-90% silica filler, 10%-20% epoxy resin, and additives and due to its low glass transition temperature (Tg) limits its use in high-temperature applications for next-generation semiconductor devices.
- Cyanate ester (CE) can improve heat resistance when added to epoxy resin, forming a copolymer network with enhanced Tg and thermal stability. And antioxidants, such as steric hindrance phenols, can be added to the cyanate and epoxy co-curing system to inhibit thermal degradation and enhance thermal stability.
- Triglycidyl isocyanurate (TGIC) addition to CE/EP copolymer increases Tg and heat resistance by increasing triazine content.





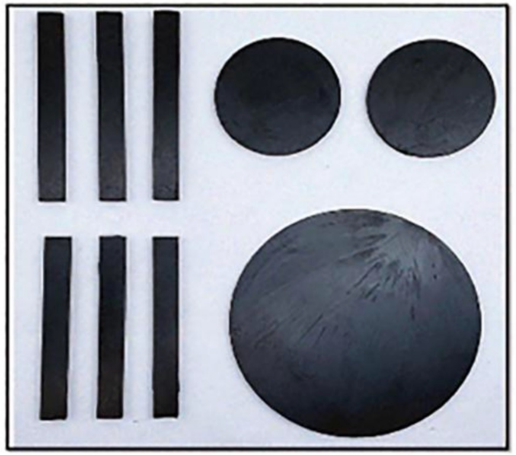


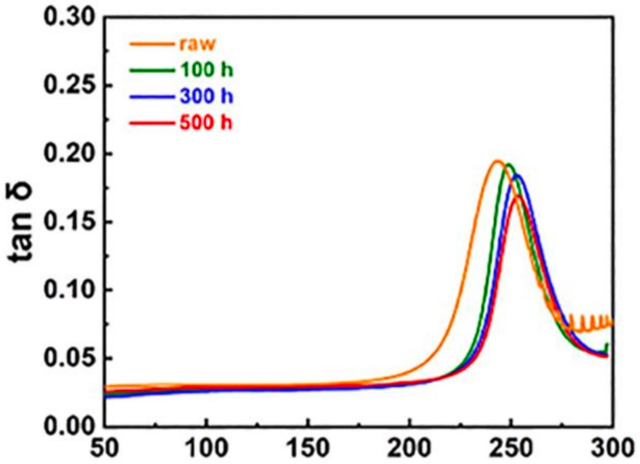


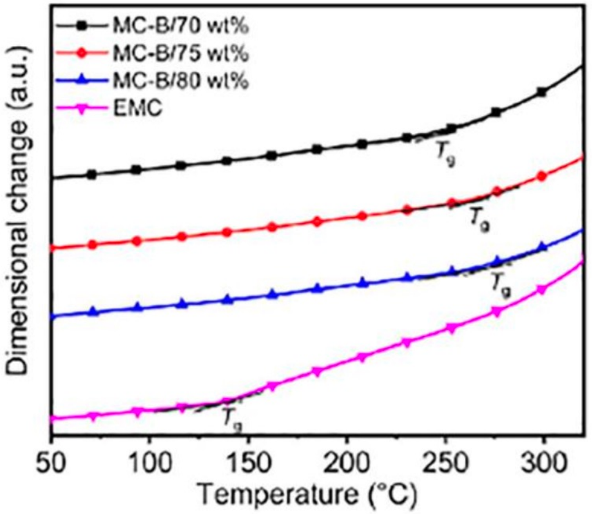
3. Inamdar, A., et al.: High temperature aging of epoxy-based molding compound and its effect on mechanical behavior of molded electronic package. Polym. Degrad. Stabil. 188, 105972 (2021). https://doi.org/10. 1016/j.polymdegradstab.2021.109572

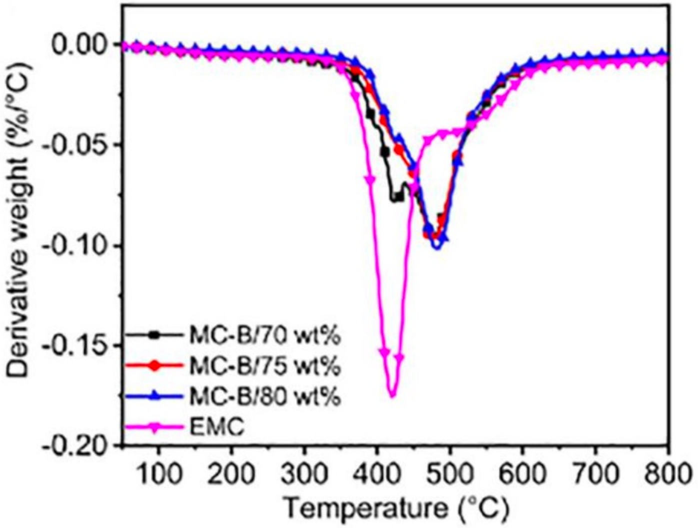
1) Moulding Compound

- Benzoxazine (BOZ) is a thermosetting resin with high Tg, modulus, and thermal stability; it can be combined with EP resin to form a high-temperature-resistant moulding
- Bismaleimide (BMI) Resins are known for excellent mechanical properties, heat resistance, moisture resistance. The processing and molding methods similar to epoxy resins.
- We can introduce BMI into a p-xylene phenolic resin (PF) and a triphenylmethane novolac EP.
- Properties of Cured BPE Moulding Compound include BMI content exceeding 70 wt% and higher Tg (>250°C) and Tm (>400°C) compared to EMC (epoxy molding compound).





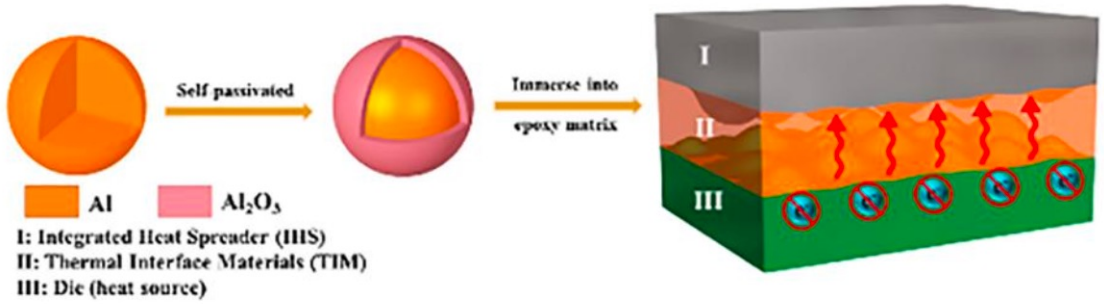


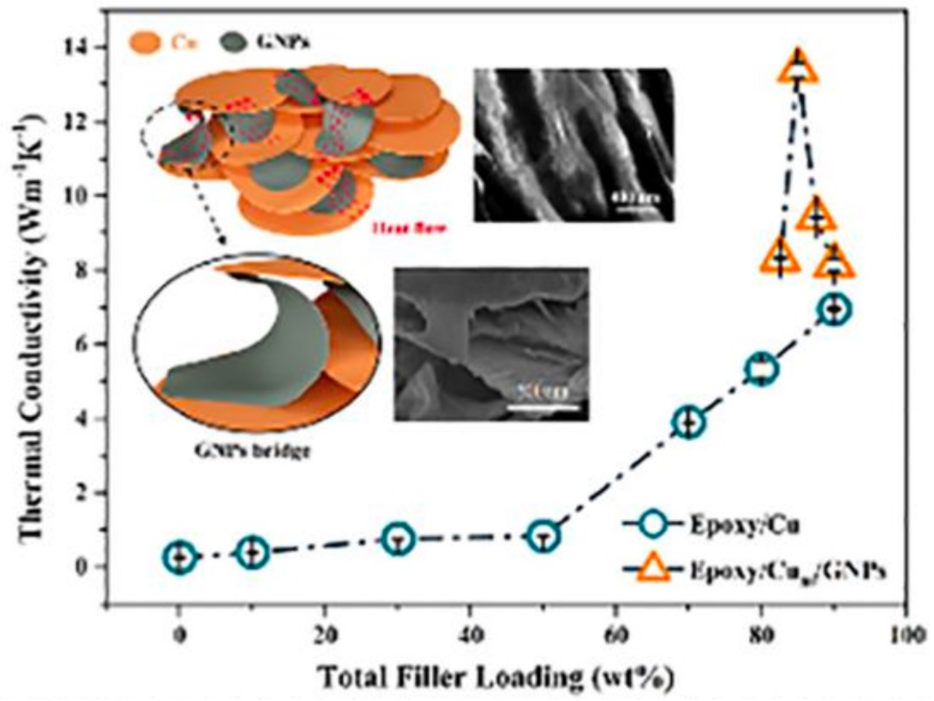


4. Wu, F., et al.: Cyanate ester/epoxy co-curing system with thermal stabilizers for high temperature stability. In: 68th IEEE Electronic Com- ponents and Technology Conference (ECTC). IEEE (2018). https://doi. org/10.1109/ECTC.2018.00336

2) Thermal Interface Material

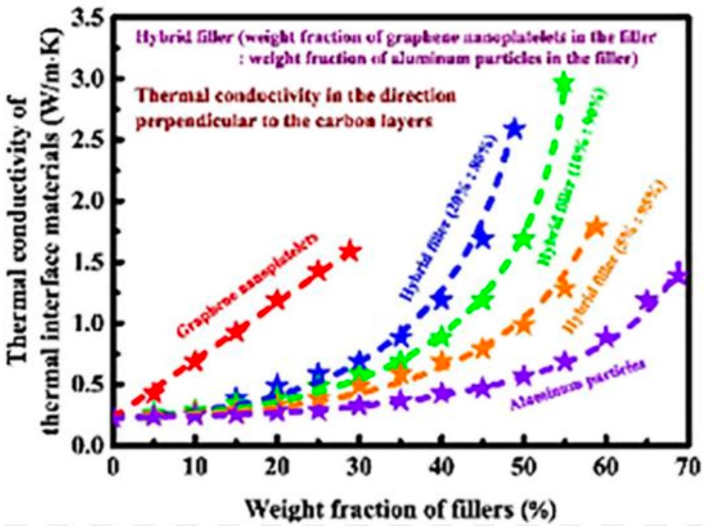
- Thermal interface material (TIM) is crucial for semiconductor device thermal management, filling micro voids to reduce thermal resistance and dissipate heat.
- Excellent TIM properties include great dispersibility, minimal volatiles, good wettability, high thermal conductivity, proper modulus, elongation, compressibility, bond-line thickness, and thermal stability.
- Polymer-based TIMs consist of a polymer matrix and thermally conductive reinforcing phases to improve overall thermal conductivity.
- Metal materials like Ag, Cu, Al are ideal fillers for TIMs with high thermal conductivity, electrical conductivity, and low CTE.
- Al and Al2O3 are commonly used; core-shell structures with in-situ growth of Al2O3 on Al particles in epoxy resin matrix enhance thermal conductivity.
- Epoxy/Cu/graphite nanoplatelets composites (ECG) with high aspect ratio exhibit extraordinary thermal conductivity through electron-phonon effect.





5. Singh, A.K., et al.: Recent developments on epoxy-based thermally conductive adhesives (TCA): a review. Polym.-Plast. Technol. Eng. 57(9), 903–934 (2018). https://doi.org/10.1080/03602559.2017.1354253

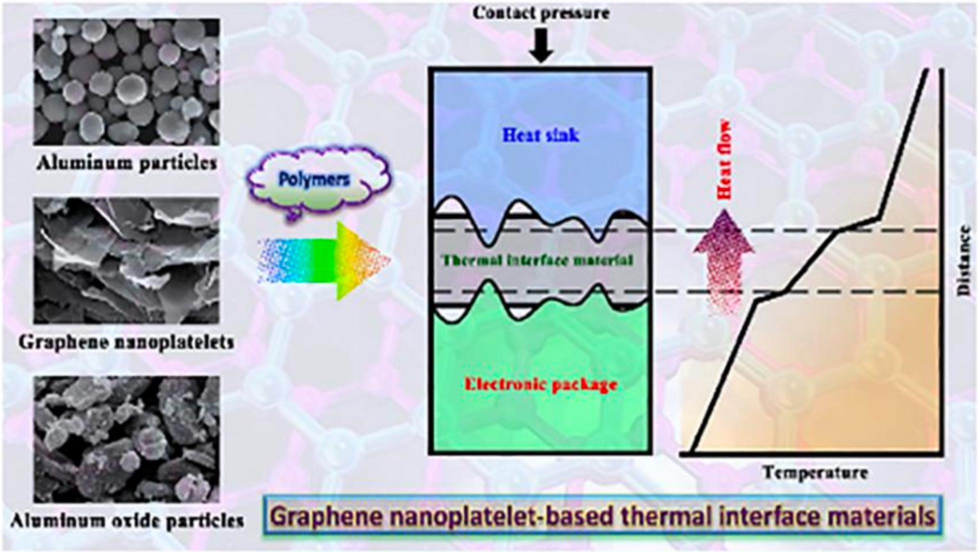
2) Thermal Interface Material-

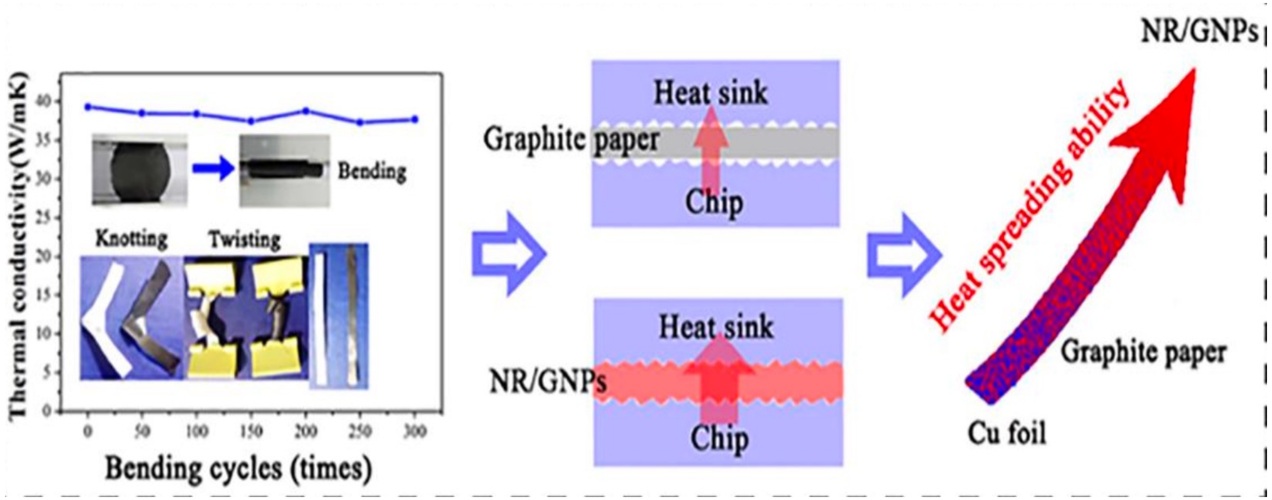


•Epoxy resin with graphene nanosheets and aluminum-based particles improves anisotropic thermal conductivity, achieving best properties with 10% graphene content.

•Thermal conductive film composites with natural rubber matrix and graphene nanoparticles show high thermal conductivity, elongation at break, low hardness, and modulus.

•Oriented boron nitride nanosheets (BNNS) in P(VDFHFP) matrix achieved 7.26 W/mK in-plane thermal conductivity with 25 vol% filler content, a 249% increase compared to randomly dispersed BNNS.

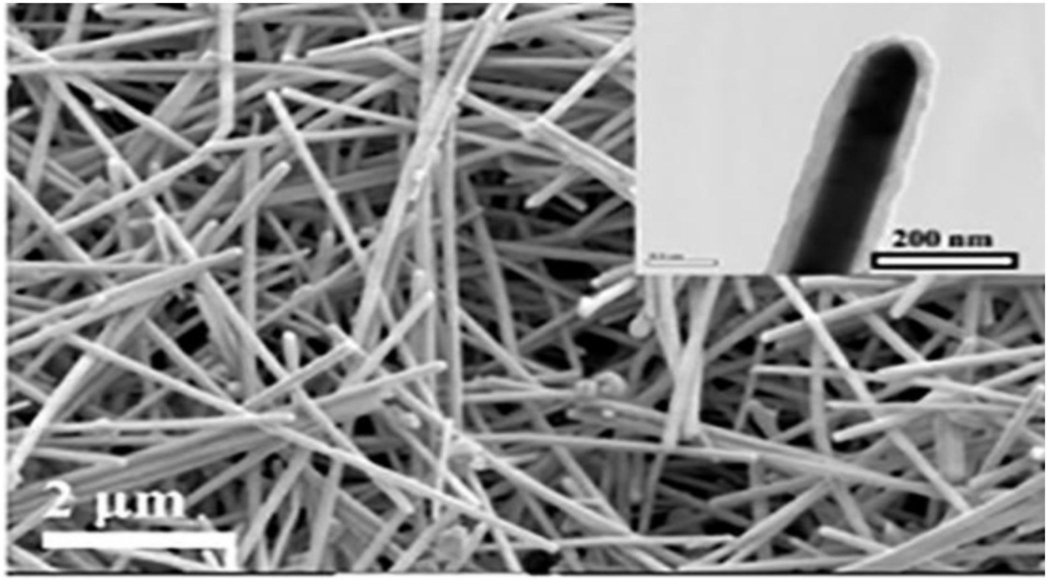


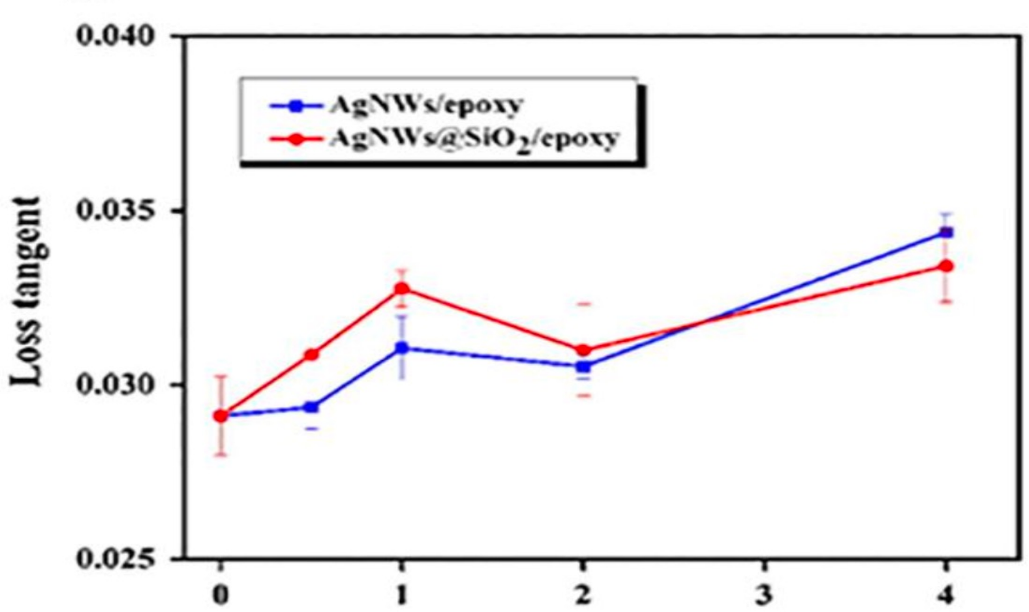


6. Chen, J., Gao, X.: Thermal and electrical anisotropy of polymer matrix composite materials reinforced with graphene nanoplatelets and aluminum-based particles. Diam. Relat. Mater. 23(12), 100–119 (2019). https://doi.org/10.1016/j.diamond.2019.107571

3) Underfills

- **Purpose of Underfill Materials:**
  - Address CTE mismatch between silicon chips and substrates in flip chip technology. And prevent thermal stress from causing solder joint failure.
- **Properties of Ideal Underfill Materials:**
  - Low viscosity for complete gap filling, Low CTE difference with solder joint.
  - High Tg for reliability at high temperatures and high thermal conductivity to reduce heat buildup.
- Challenges with Ag Nanowires (AgNWs) include High aspect ratios and thermal conductivity, Hydrophilic surface affects dispersion and high electrical conductivity limits semiconductor packaging application.
- Solution by author is coating uniform SiO2 nanolayers on AgNWs' surface. This improved phonon mismatch, reduced thermal interfacial resistance, and blocked conductive networks, resulting in EP/AgNWs@SiO2 underfill composites with good thermal conductivity (1.030 W/mK).





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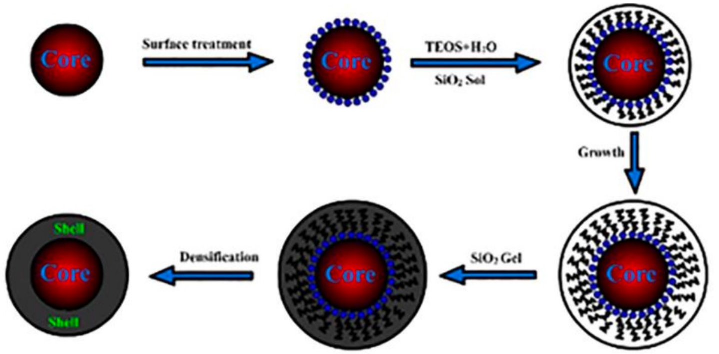
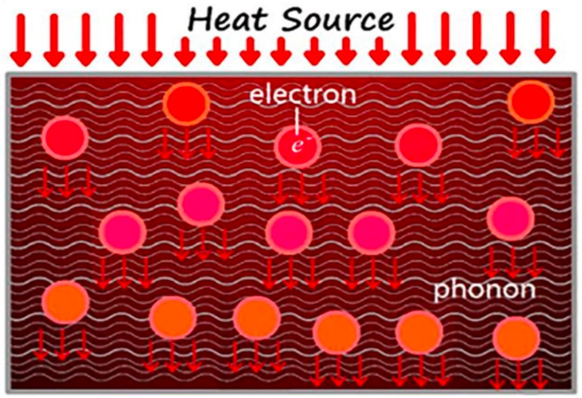
3) Underfills-

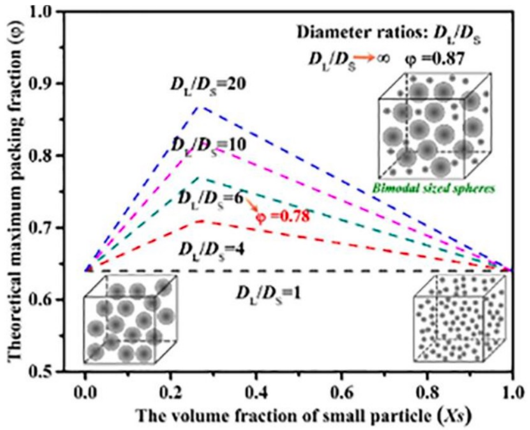
• Copper Nanoparticles wrapped by silica in EP Matrix- Introduced by Li et al., overall thermal conductivity of 2.9 W/mK. Also results in prolonged IC service life by 16.5 times.

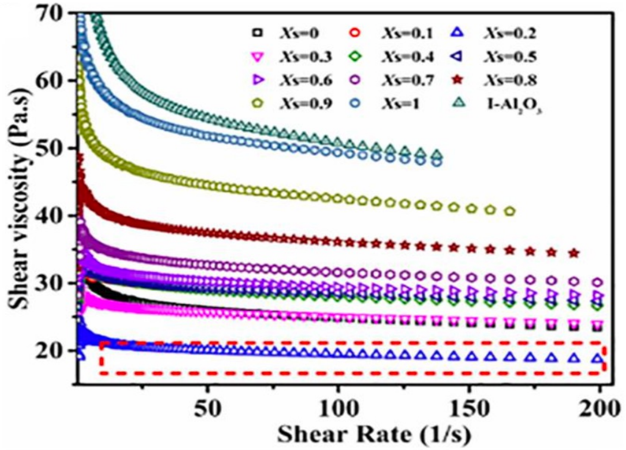
• EP composites with spherical alumina by Chen et al achieves low viscosity, high thermal conductivity, and comparable CTE to solder.

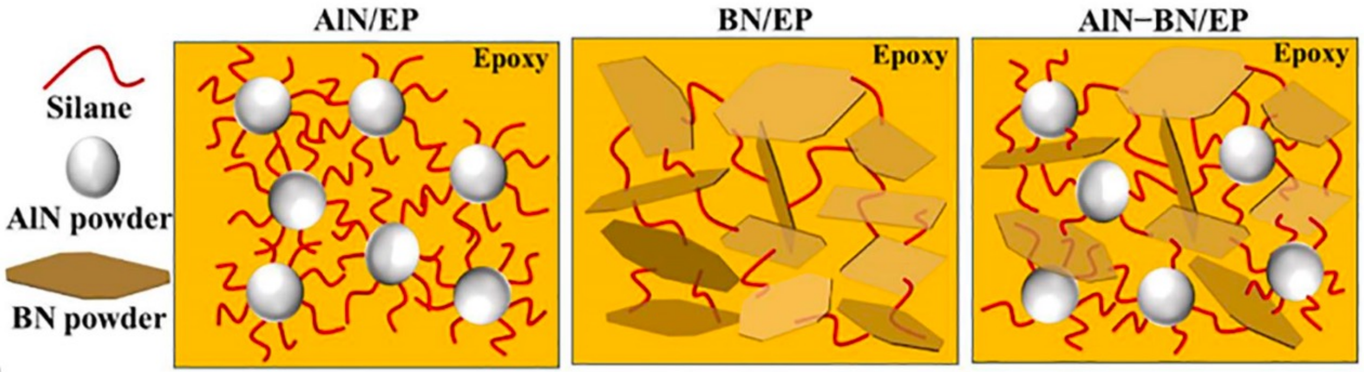
•Hybrid fillers (AlN and BN sheets) resulting in underfill composites with excellent thermal conductivity, low CTE, low dielectric loss tangent, and high viscosity.











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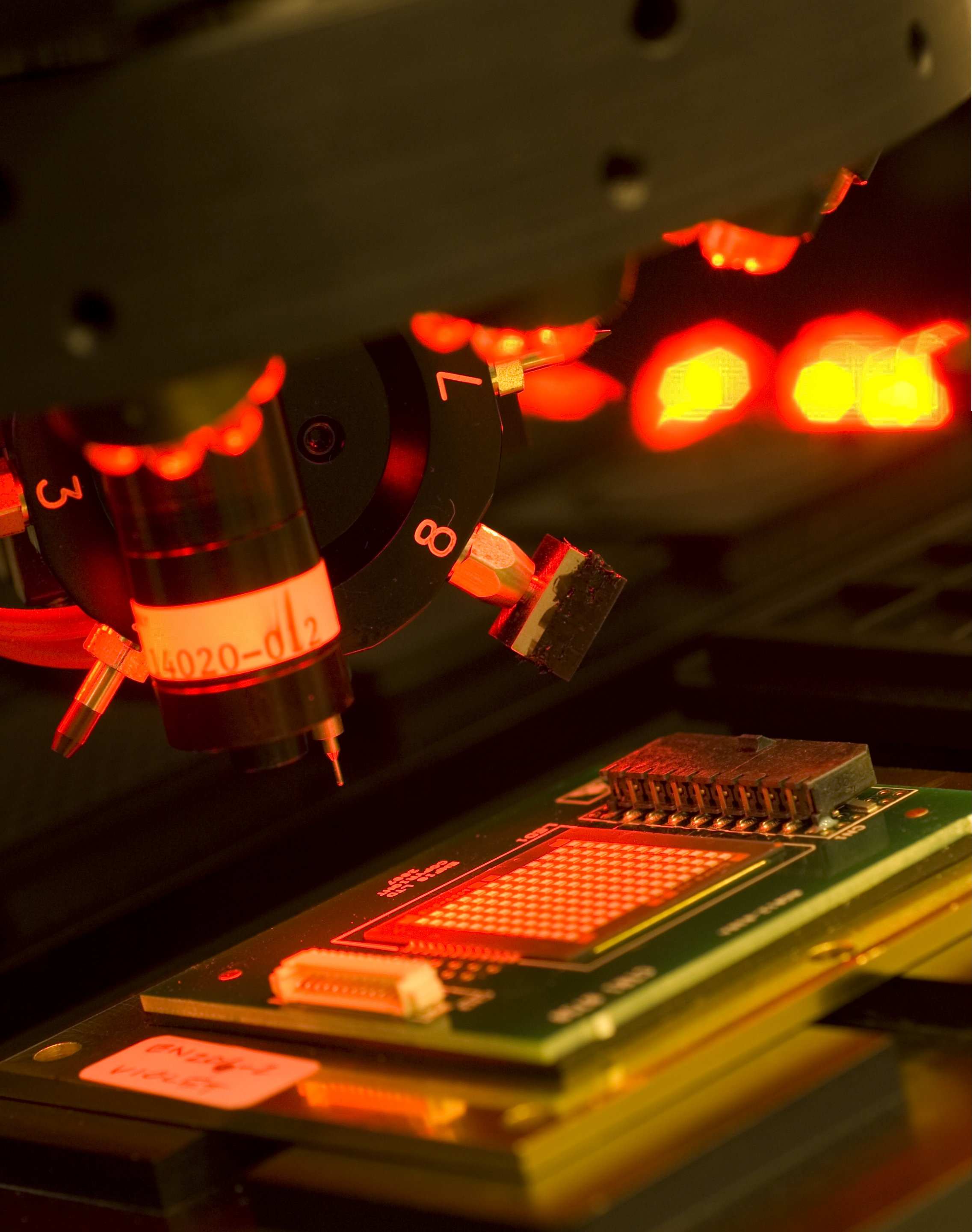


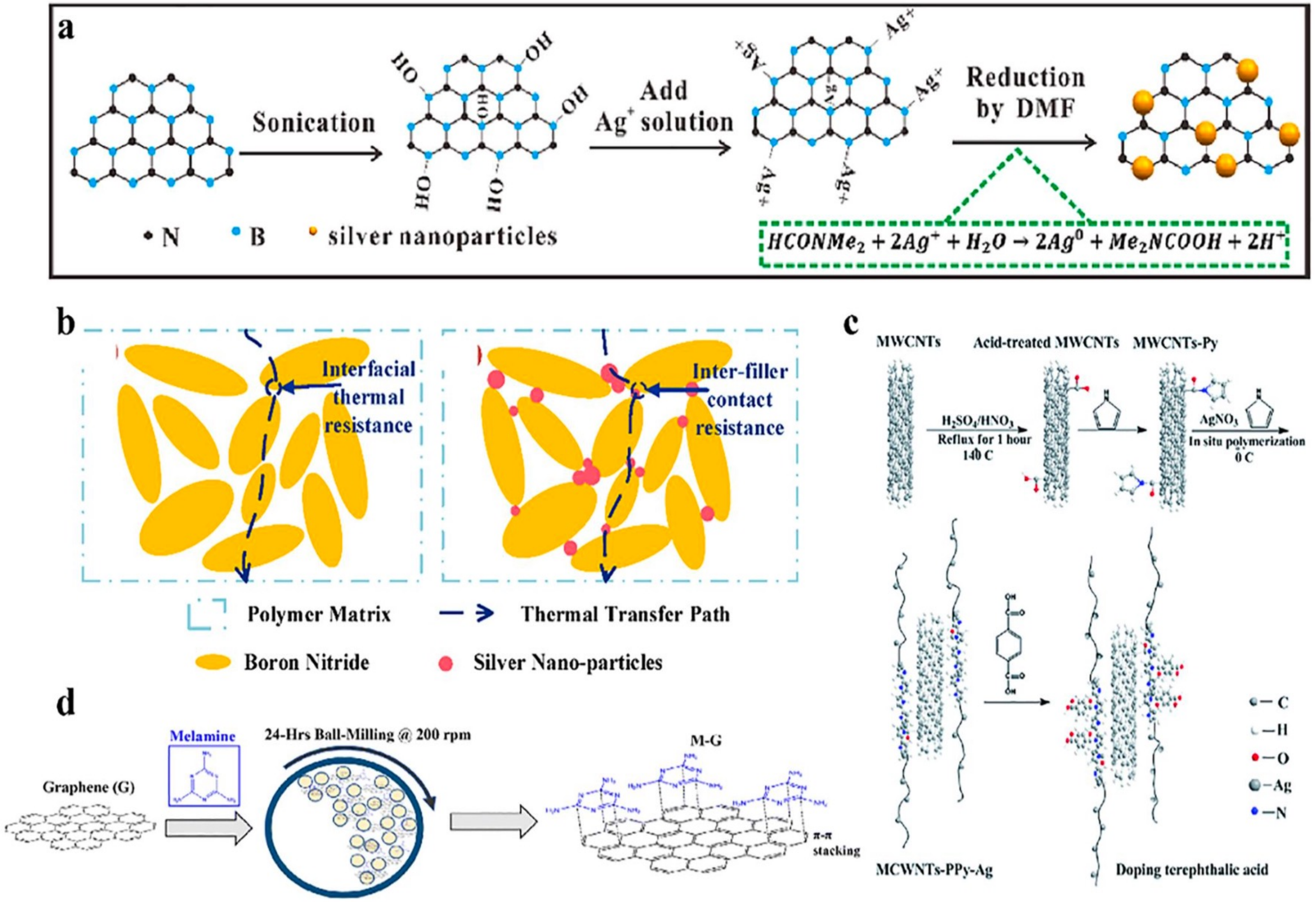
4) Die attach materials

- Purpose of Die Attach Materials is to Bond chips and substrates in wire bonding packaging technology.
- Desirable Properties of Die Attach Materials include high purity to prevent contamination, fast curing and low stress to reduce CTE mismatch.
- Common Die Attach Materials are polymer-based nanocomposites with fillers like Ag and SiO2. The matrix options include epoxy, polyimide, acrylate, and silicone.
- Silver Pastes for Die Attachment consist of silver fillers and epoxy resins and thermal curing used for chip attachment. But high cost of silver poses economic challenges.

9. Zhang, Z., et al.: Low-temperature and pressure less sinter joining of Cu with micron/submicron Ag particle paste in air. J. Alloys Compd. 780, 435–442 (2019). https://doi.org/10.1016/j.jallcom.2018.11.251

4) Die attach materials-

- **Enhancements and Cost Reduction:**
  - Addition of low-cost fillers to reduce silver content.
  - Fu et al. and Wu et al. added BN to EP-containing Ag nanoparticles, reducing Ag content and increasing thermal conductivity (0.804 W/mK and 2.14 W/mK).
  - Wang et al. incorporated terephthalic acid-doped MWCNTs with silver nanoparticle-decorated poly-pyrrole functional coatings as fillers, achieving a thermal conductivity of 0.47 W/mK at 10 wt% filler content.
  - Sun et al. prepared melamine-functionalized graphene-epoxy composites with a non-destructive ball milling process, resulting in a Tg of 172°C and thermal conductivity of 1.08 W/mK at 10 wt% filling.

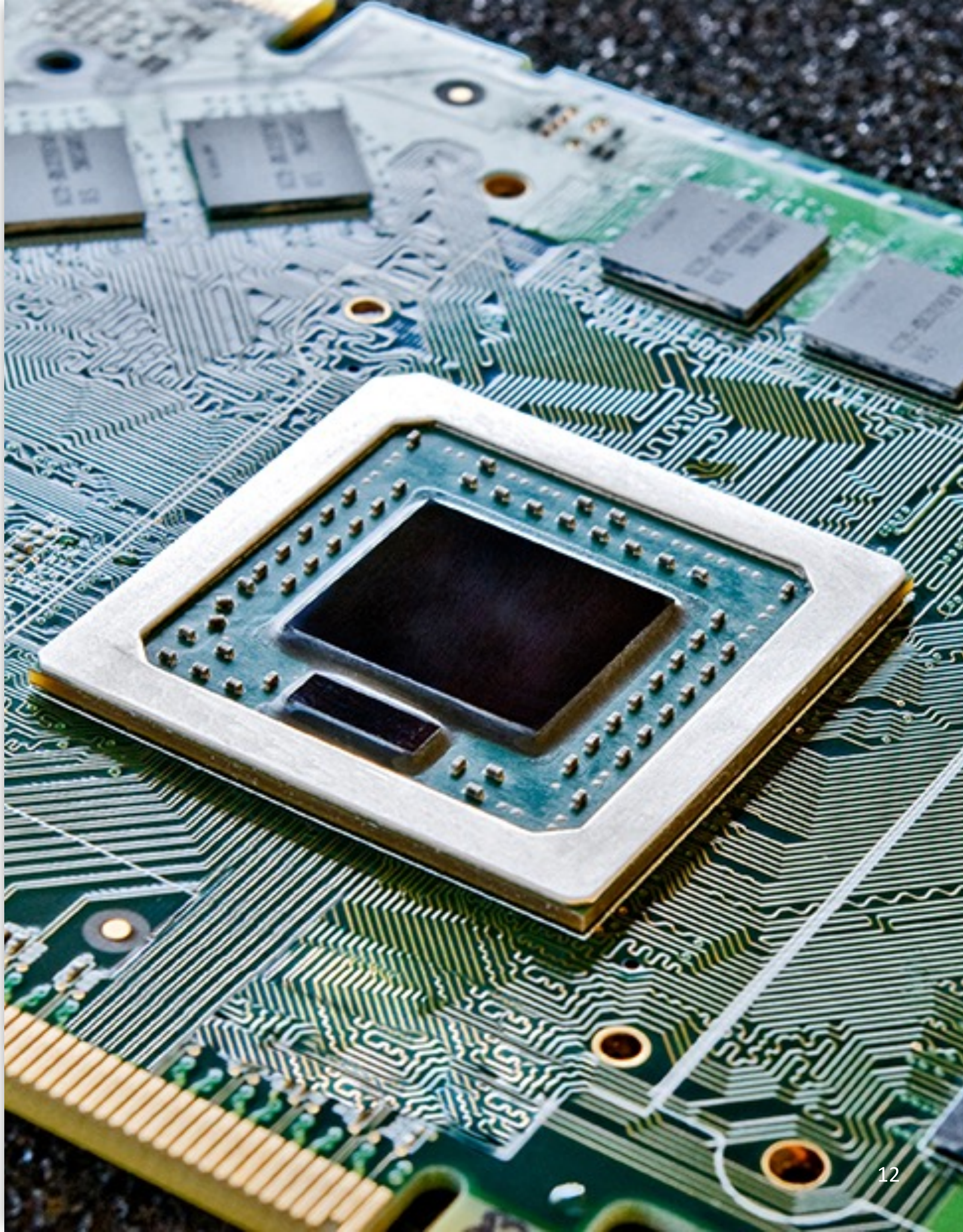


10. Fu, C.J., et al.: Improving thermal conductivity through welding boron nitride nanosheets onto silver nanowires via silver nanoparticles. Compos. Sci. Technol. 177, 118–126 (2019). https://doi.org/10.1016/j.compscitech.2019.04.026

5) Substrates

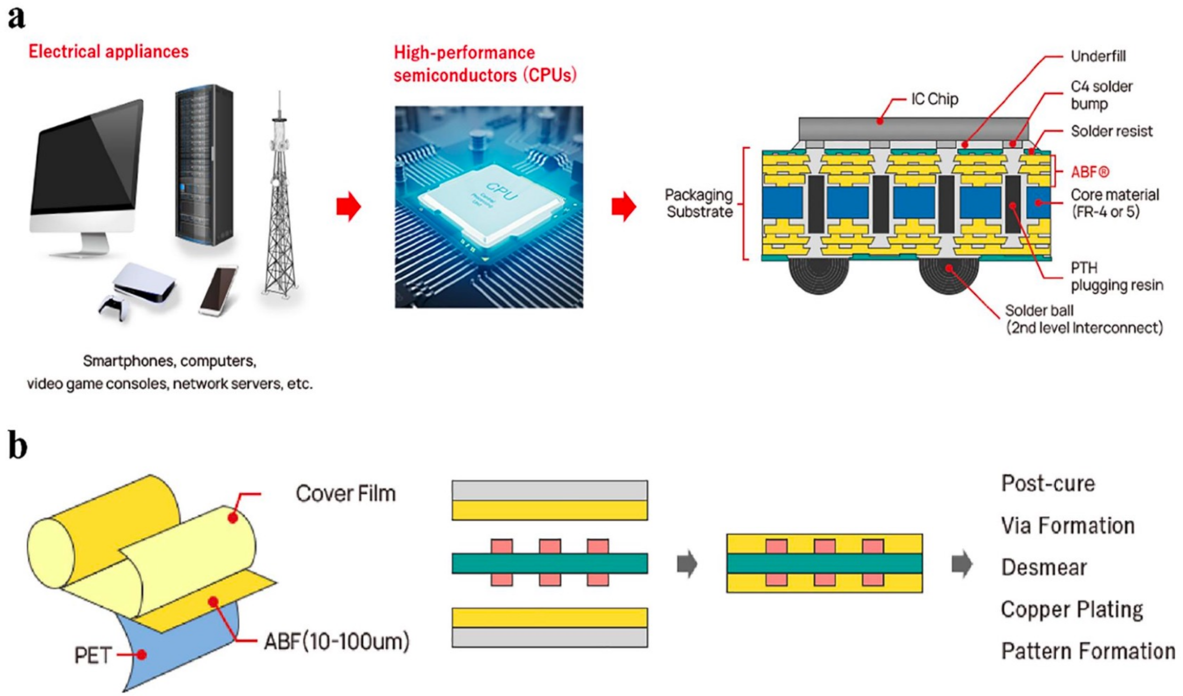
- Packaging substrates serve as high-end PCBs with specific requirements.
- Line/space sizes in packaging substrates are often <15 μm/15 μm, supporting chip, guiding electrical pathways, providing protection, and aiding heat dissipation.
- Substrate fabrication processes: subtractive, semi-additive, and additive.
- Semi-additive process allows for ultra-fine line/space (<10 μm/10 μm), suitable for miniaturized semiconductor components.
- Buildup Film (BF) in semi-additive process has low CTE, dielectric loss, moisture absorption, high Tg, and great mechanical properties.
- BF-based substrates, e.g., in FCBGA technology, use bismaleimide-triazine (BT) core and BF double-sided build-up layers.

11. Yang, J., et al.: Thermally stabilized bismaleimide-triazine resin compos- ites for 10-GHz level high-frequency application. High Perform. Polym. 30(7), 833–839 (2018). https://doi.org/10.1177/0954008317732396

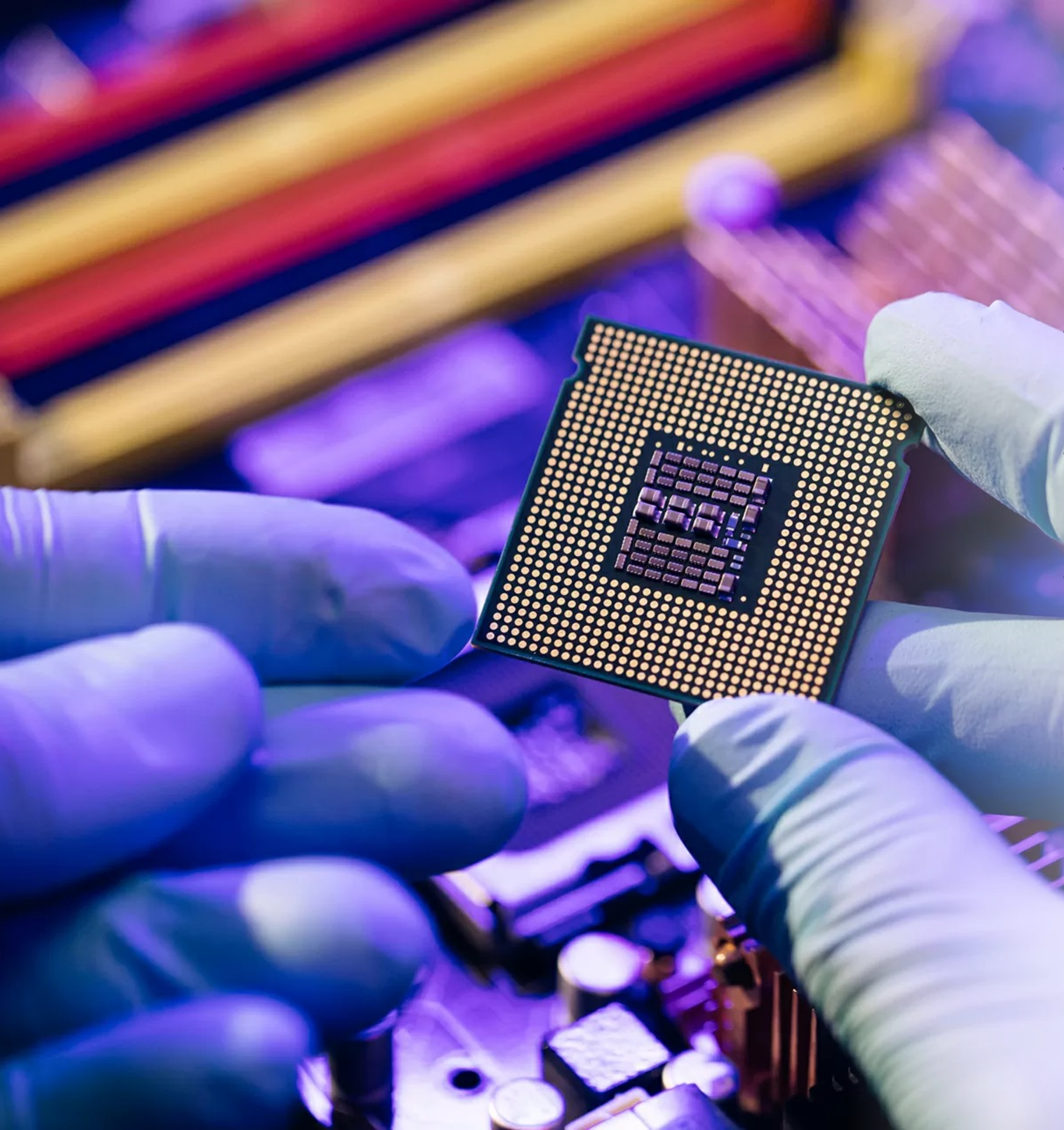


5) Substrates-

•Plated copper on BF reduces substrate thickness, rationalizes layer layout, and eases laser drilling.
•Researchers achieved fine line (5 µm/5 µm) redistribution layers on BT core using BF.
•BF as isolation layer in silicon substrate reduces electromagnetic field interaction, lowering in-band insertion loss.
•For 5G and higher frequencies, ABF/Glass/ABF substrate with laminated 15 µm BF shows low dielectric loss.
•Flexible substrates gaining popularity for flexible semiconductor devices.
•Polymeric materials like PDMS, PC, and PI used for flexible substrates due to high stiffness, light weight, and durability.



12. Nie, S., et al.: Soft, stretchable thermal protective substrates for wearable electronics. NPJ Flex. Electron. 6(1), 36 (2022). https://doi.org/10. 1038/s41528-022-00174-8



Summary

- Semiconductor packaging materials evolving with advancements in integration, miniaturization, and functionalization and polymer-based materials favored for low cost, simple processability, and tunability.
- Challenges include achieving lower dielectric constant and loss, lower CTE, higher Tg, thermal conductivity, lower water absorption, and suitable viscosity.
- Research focuses on synthesizing superior matrixes and fillers, exploring filler-matrix interface for material enhancement.
- Key issues in developing novel packaging materials:
    - Balancing trade-off between performance and manufacturing cost on a large scale.
    - Improving dispersion of inorganic fillers in the polymer matrix for enhanced thermal, dielectric, and mechanical properties.
    - Developing a realistic theoretical model for the filler-matrix system to predict composite performance and suggest practical applications.

13. Polymer-based nanocomposites in semiconductor packaging DOI: 10.1049/nde2.12050

REFERENCES-

1. Wan, Y.-J., et al.: Recent advances in polymer-based electronic packaging materials. Compos. Commun. 19, 154–167 (2020). https://doi.org/10. 1016/j.coco.2020.03.011

2. Chen, M.Q., et al.: The preparation of high-volume fraction SiC/Al composites with high thermal conductivity by vacuum pressure infiltra-tion. Crystals 11(5), 515 (2021). https://doi.org/10.3390/cryst11050515

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REFERENCES-

7. Hu, Y., et al.: Novel micro-nano epoxy composites for electronic pack- aging application: balance of thermal conductivity and processability. Compos. Sci. Technol. 23(15), 209–212 (2021). https://doi.org/10.1016/j.compscitech.2021.108760

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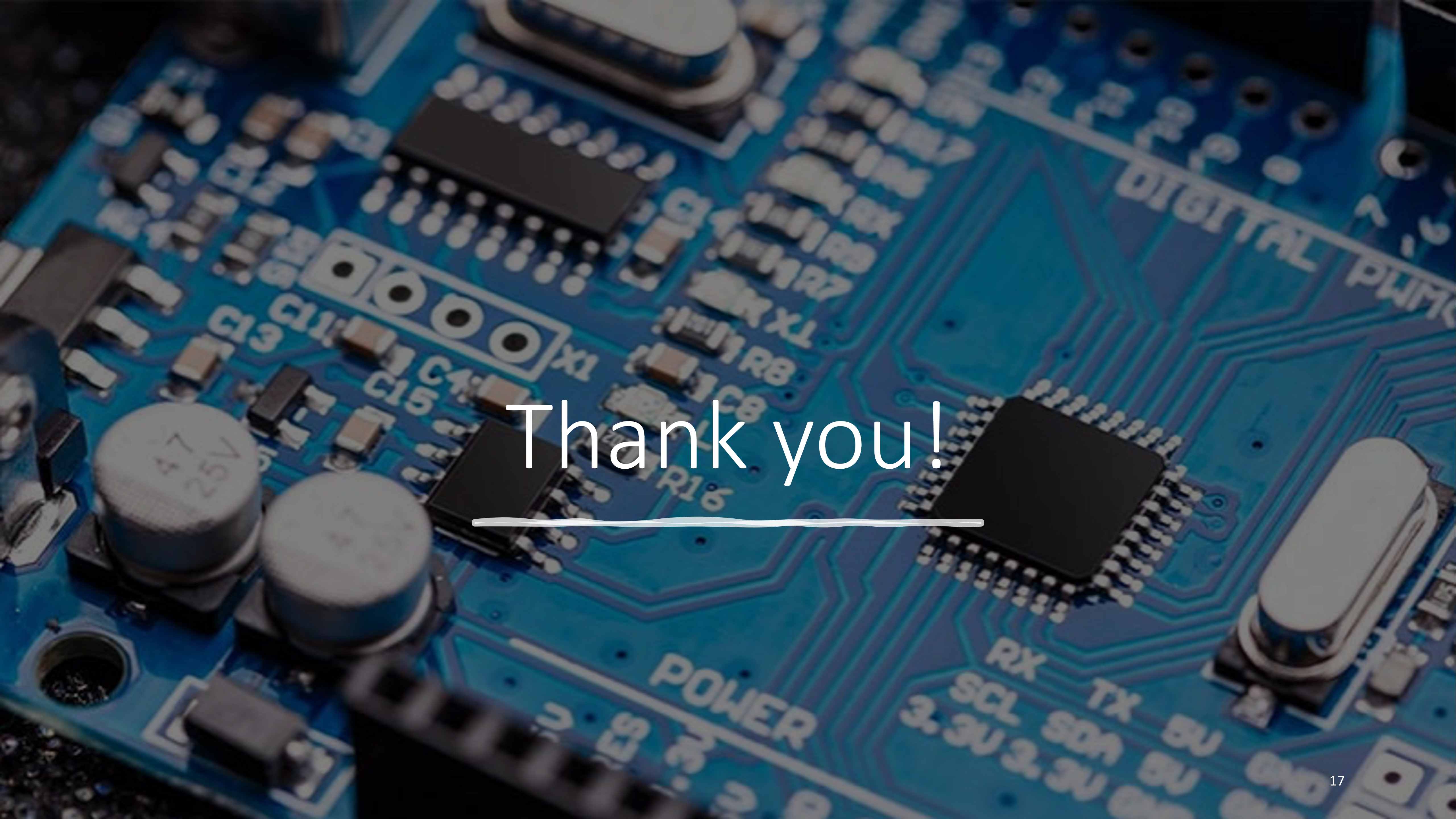

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