Mobile Antennas and Power Devices that Break the Mold

Laser Direct Structuring and Liquid Semiconductor Encapsulants
May Hold the Key to Increased Function for Certain Applications

Henkel Corporation and LPKF Laser & Electronics AG

As mobile 5G and 6G electronics advance and data traffic explodes, innovation in IC designs to incorporate expanded function, improved high-frequency shielding performance, better reliability and lower power consumption are required. To enable the ongoing miniaturization of mobile devices in combination with improved performance, new techniques that leverage existing architectures to integrate additional active electrical function have been explored. One application is the mobile antenna. Data send and receive signals in mobile devices are managed, in large part, through the mobile antenna. If antenna real estate could be allocated from existing structures by leveraging the IC's mold compound to add active electrical functionality, then even more capability can be integrated into current device footprints.

With this technique, known as active mold packaging (AMP), unutilized areas of the IC package's epoxy mold compound (EMC) are allotted for metallization layers to deliver an alternative for mmWave applications. Using the standard well-known electronic processes of EMC, laser technology for laser direct structuring (LDS), and additive copper metallization, circuits can be created for various applications. (**Figure 1**) This AMP approach with LDS technology is used today and is well-understood. However, the challenges with current processes center around limitations with the mold materials. All available EMC materials for LDS are granular or powder-like solids that have difficulty achieving thin layers, are not automation- and cleanroom-friendly, and may pose health and safety concerns.

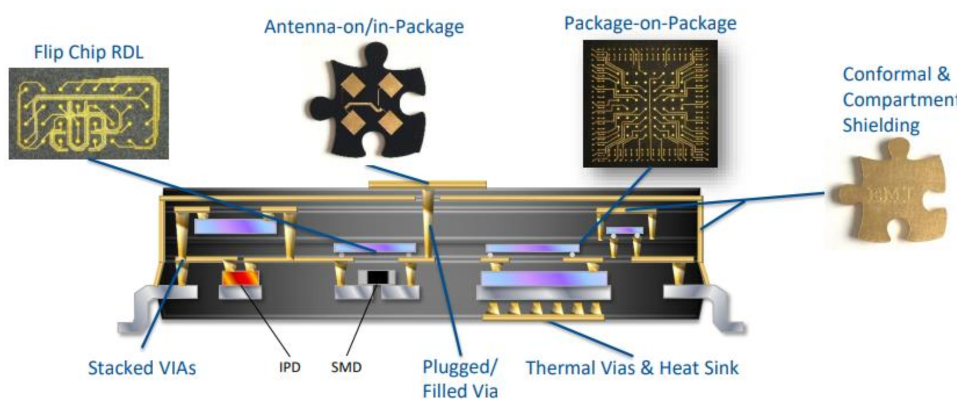

Figure 1. Potential Active mold packaging (AMP) applications through electrical circuitry integration directly inside and onto a molded package.

THINNER, FASTER, SAFER MOLDING TECHNOLOGY

Tackling the challenges of liquid compression mold materials for semiconductor applications, Henkel has developed anhydride-free (SVHC-free, as defined by REACH), low-warpage liquid mold compound encapsulants. Two different material platforms were formulated and scaled up: A liquid compression molding (LCM) material for a compression mold process and a printable encapsulant compatible with the stencil printing process. Both materials were reformulated to incorporate LDS capability and offer several advantages, including:

- Ability to achieve thinner encapsulant layers down to 50 µm with 15-25 µm/15-25 µm line/space resolution and fine vias of <50 µm to enable significantly smaller antenna designs for power and RF applications.
- Suitable for wafer and/or panel-level processing with low warpage after cure and redistribution layer (RDL) processing.
- Low-stress and dust-free alternative to powder/granular materials that require higher force during the application process and extra precautions in cleanrooms.

Using these new Henkel-developed LDS encapsulants and LPKF laser technology, a study was conducted to evaluate the performance of the LCM LDS and printable LDS materials for the creation of 5G mmWave antenna packaging. In both cases, LDS additives were integrated into the materials, which had no measurable impact on the formulations' dispensing, printing, coverage, cure, and material properties, enabling a drop-in approach with current high-volume manufacturing processes and little to no modification.

Figure 2 illustrates the process for LCM LDS compression molding and printable LDS stencil printing, as well as laser ablation and plating. **Figure 3** shows the post-processing plated LCM-LDS. After processing and cure, each molded and cured 8” silicon (Si) wafer demonstrated warpage of less than 1.0 mm across the wafer. As a next step, the laser is used to surface structure the antennae onto the compound and laser drill the vias to connect them to the encapsulated Tx/Rx module. Finally, the wafer or panel undergoes electroless copper (Cu) metallization. During this step, the Cu will grow selectively on the laser-structured areas of the compound only. In addition to the design flexibility, improved quality and lower costs this technique affords, it also enables ultra-fine structures with very thin laser-defined Cu tracks and gaps and through-mold vias (TMVs). Because the current-carrying copper layer tends to oxidize quickly, an RF-compatible, thin silver layer was applied to protect it from oxidation. For different applications, various finishes such as electroless nickel immersion gold (ENIG) and electroless nickel electroless palladium immersion gold (ENEPIG) might be more suitable and can also be plated using this method.

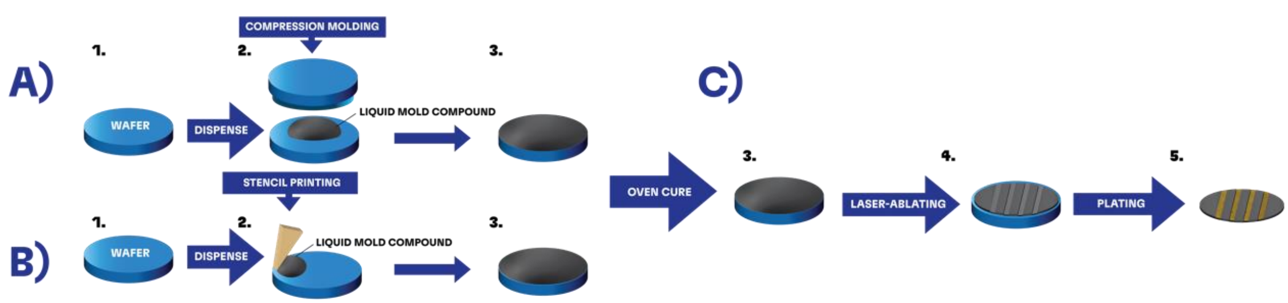

Figure 2. a) Liquid compression molding encapsulation process; b) Stencil printing encapsulation process; c) Laser-structuring (ablation and via drilling) and plating process.

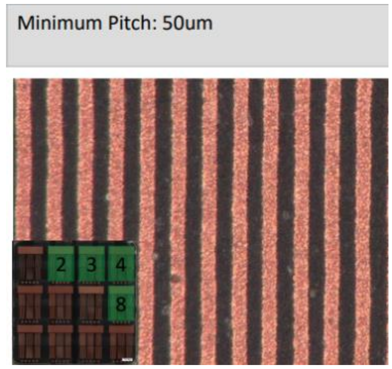

Figure 3. Optical image of plated LCM-LDS with 50 µm pitch.

Once the laser parameter processing window was established for Cu plating speed and adhesion, which are the general measures of success, adhesion strength of the printable LDS, the LCM LDS and the reference (granular/solid epoxy) LDS were evaluated using a hot pin pull test. The results are shown in **Figure 4**. Based on this evaluation, little statistical difference in adhesion strength between the various compounds was observed. However, the LCM LDS material exhibits consistently higher adhesion values than the other two material types.

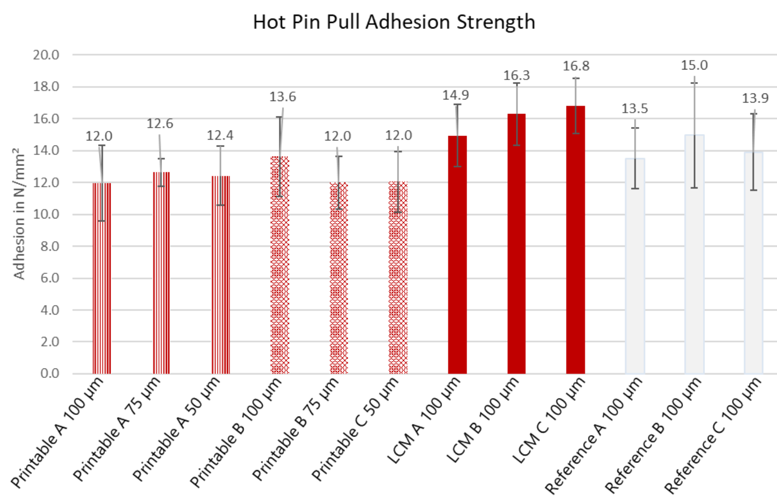

Figure 4: Plated Cu adhesion comparison of different LDS materials: printable LDS, LCM LDS and granular/powder LCM. (Reference materials A, B and C are conventional powder/granular compounds.)

BEYOND THE SIGNAL: WIRE BOND REPLACEMENT, THERMAL CONTROL AND EMI SHIELDING

While the initial intent was to explore the creation of active electrical function for 5G antenna structures, the AMP technique presents opportunities for a variety of applications that may benefit from the technology's ability to facilitate further miniaturization objectives. Some of these include, but are not limited to:

- Replacement of traditional wire bonds with ‘flat bonds’
    - Flat interconnection between the die and the substrate or leadframe, which leads to lower current requirements and higher operating frequencies. (**Figure 5**)

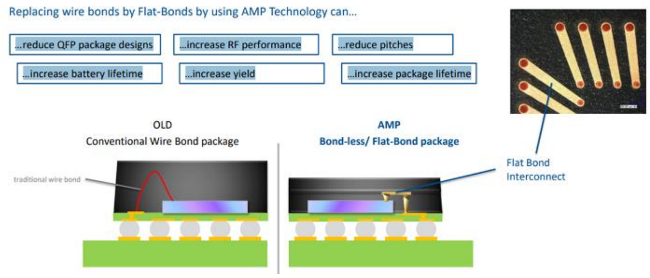

Figure 5: Flat bonds achieved via AMP are a potential replacement for wire bonding.

- Antenna-on/in-Package
    - Eliminates the current design transducer and antenna module design by including the antenna directly on or in the transducer.

- Thermal management
    - Thermal vias and solderable surfaces can be created through laser via drilling and laser surface ablation for heat dissipation and the addition of heat sinks to the solderable surface. (**Figure 6**)

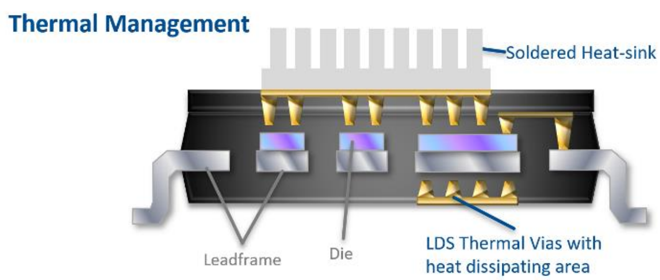

Figure 6: Improved thermal management for RF or high-power modules.

- EMI shielding
    - Ability to create a 30dB highly-effective, five-sided (trench or via fencing) conformal and/or compartment EMI shield.

AMP using plateable compounds represents a highly-efficient approach to expanding the electrical function – as well as offering EMI and thermal protection mechanisms – of IC packages without enlarging the footprint and, in many cases, allowing reduction of overall package dimensions. The 25 µm/25 µm line/space resolution capability and 50 µm via range of current processes is an excellent baseline, with LCM LDS and printable LDS playing an integral role as enablers of thin layers and vias in an automated process versus conventional approaches. Using the successful materials from this work, future development will focus on reducing the line width to 15 µm, which LPKF has already demonstrated. (**Figure 7**)

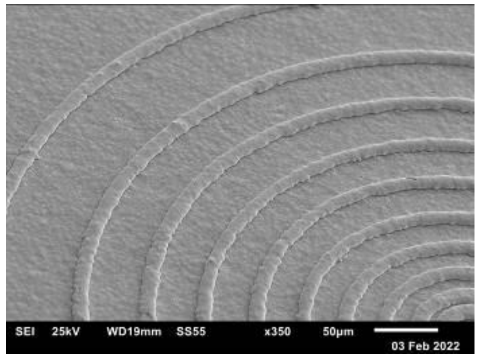

Figure 7: Electroless Cu line width of ~15 µm demonstrated by LPKF on LCM LDS encapsulant.

Based on the serious interest and engagement with over ten global semiconductor companies, Henkel and LPKF continue to further support this liquid LDS technology and optimize the process in alignment with customers' requirements in the power and RF space.

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