

# Application of Laser Welding Technology in Power Module

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## INTRODUCTION

Driven by high-performance computing (HPC) and electric vehicle demands, modern System-in-Package (SiP) designs face extreme electro-thermal stress, causing traditional solder joints to fail via thermo/electro-migration and CTE mismatches. Consequently, direct metal welding has emerged as a necessary solderless alternative. While ultrasonic welding lacks scalability, precision laser welding (LW) provides an automatable, robust solution. LW minimizes the heat-affected zone (HAZ), significantly improves shear strength, and eliminates solder-related reliability issues in next-generation power electronics.

## EXPERIMENTAL

### 1. Solder Attachment

Conventional SAC305 solder joined the lead frame and die to the copper pad of an AMB ceramic substrate, providing good electro-thermal reliability (Fig. 1a). Reflow was performed at 260°C, exposing the entire assembly to high temperatures.

### 2. Ultrasonic Welding (USW)

A 20–40kHz ultrasonic generator bonded clamped copper terminals via tangential vibrations. This dispersed surface oxides, enabling solid-state metallurgical bonding without melting (Fig. 1b). Parameters (150–350N force, <1000ms duration) were optimized with real-time monitoring to achieve >40 MPa shear strength without substrate damage.

### 3. Laser welding (LW)

A nanosecond pulsed laser joined copper terminals. Comparing wavelengths, green lasers (532 nm) showed superior initial copper absorption (~40%) for higher efficiency (Fig. 2a). Infrared lasers (1070 nm) start at ~5% absorption but jump to 15% upon melting, allowing effective penetration (Fig. 2b). The system was configured to optimize these optical-thermal properties.

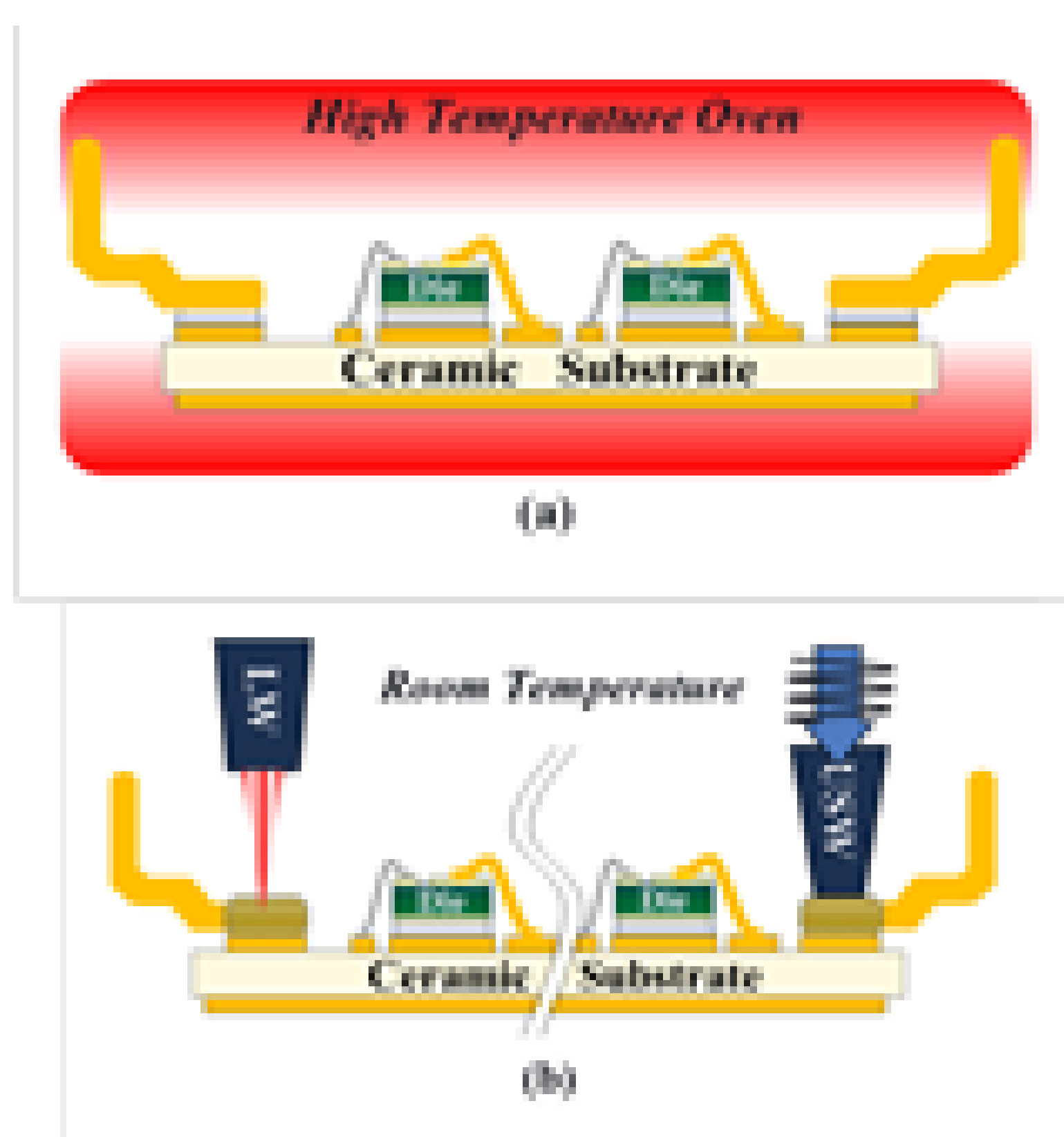


**Fig. 1** Interconnection forming: (a) conventional soldering under reflow; (b) welding by various energy delivery at connection interface

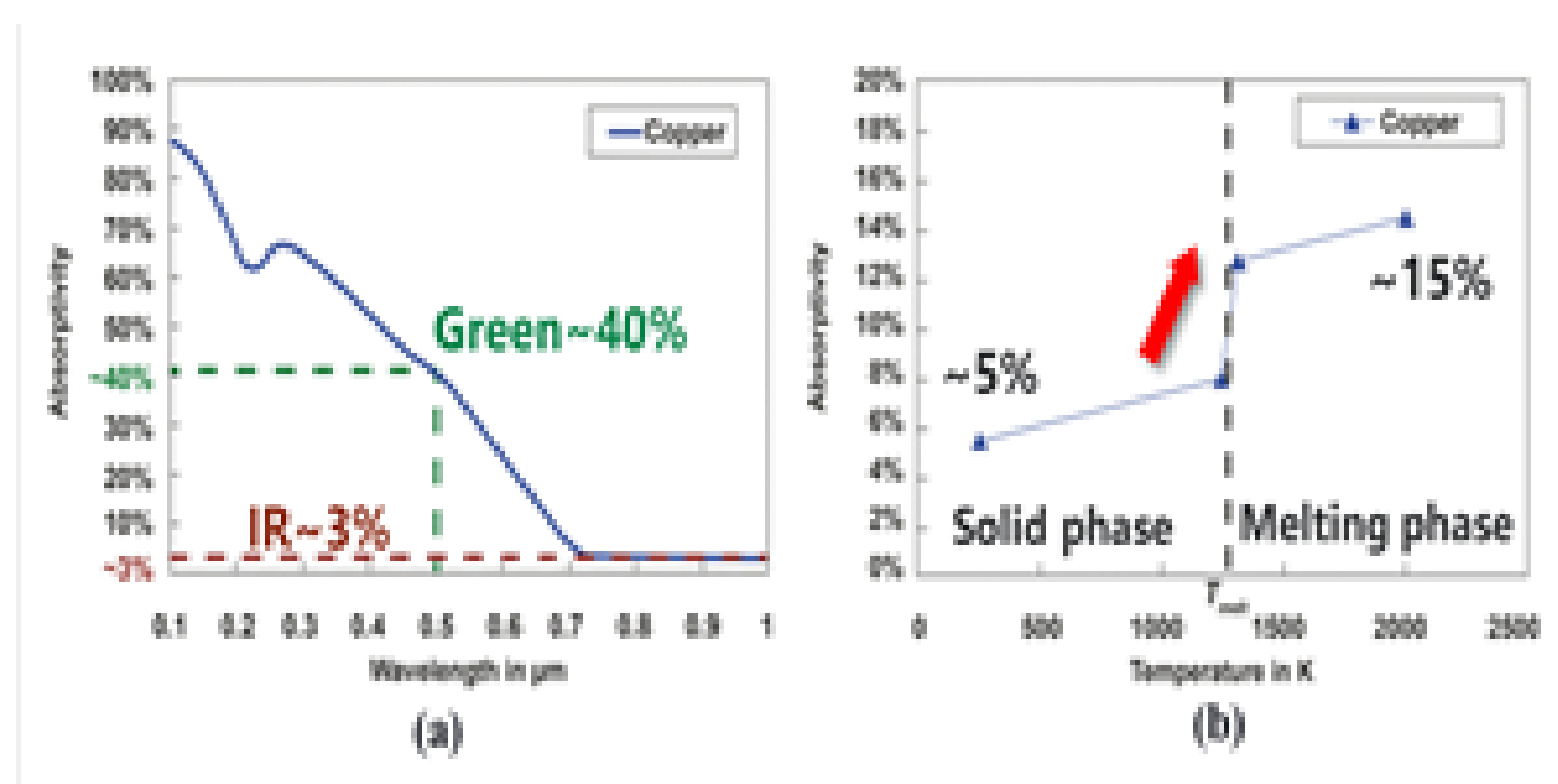


**Fig. 2** Laser absorption rate : (a) under various light [8]; (b) Higher IR laser absorption in melting phase [9].

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## RESULTS AND DISCUSSION

Initial IR laser welding of copper terminals caused severe instabilities (spatter, voids, large-grained regrowth) due to high reflectivity (Fig. 3). Conversely, green lasers achieved uniform, spatter-free joints (Fig. 4), making wavelength optimization critical for SiP modules. Furthermore, laser welding (LW) mechanically and electrically outperforms soldering and ultrasonic welding (USW) (Fig. 5). LW achieves a 155.19 MPa shear force—surpassing soldering and USW by 130% and 60%, respectively. Electrically, LW halves contact resistance ( $\sim 0.47 \text{ m}\Omega \cdot \text{mm}^2$ ). While solder fails at 800 mA, LW remains highly stable, proving optimal for demanding xEV and HPC applications.

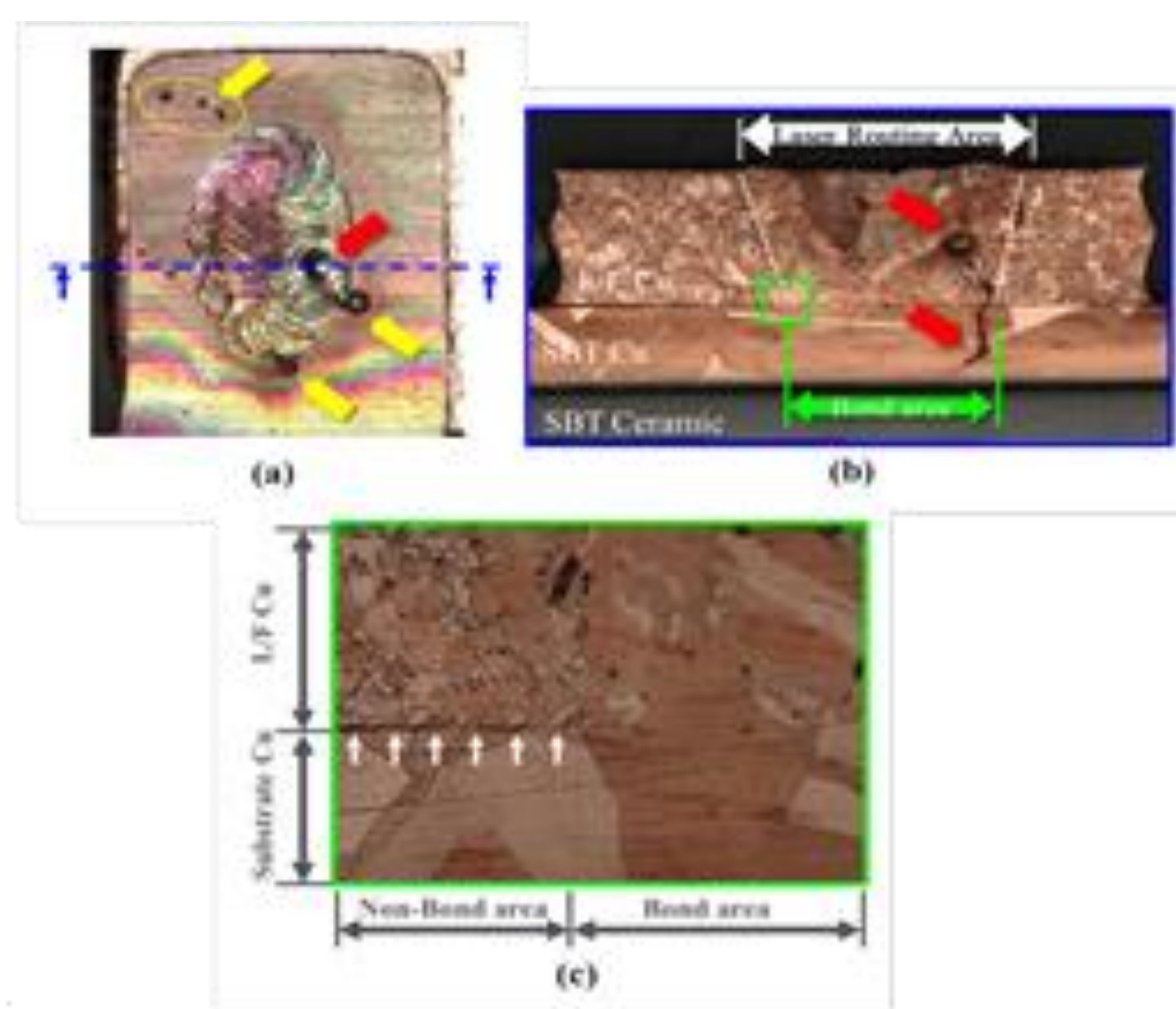


**Fig. 3:** IR laser defects & metallography

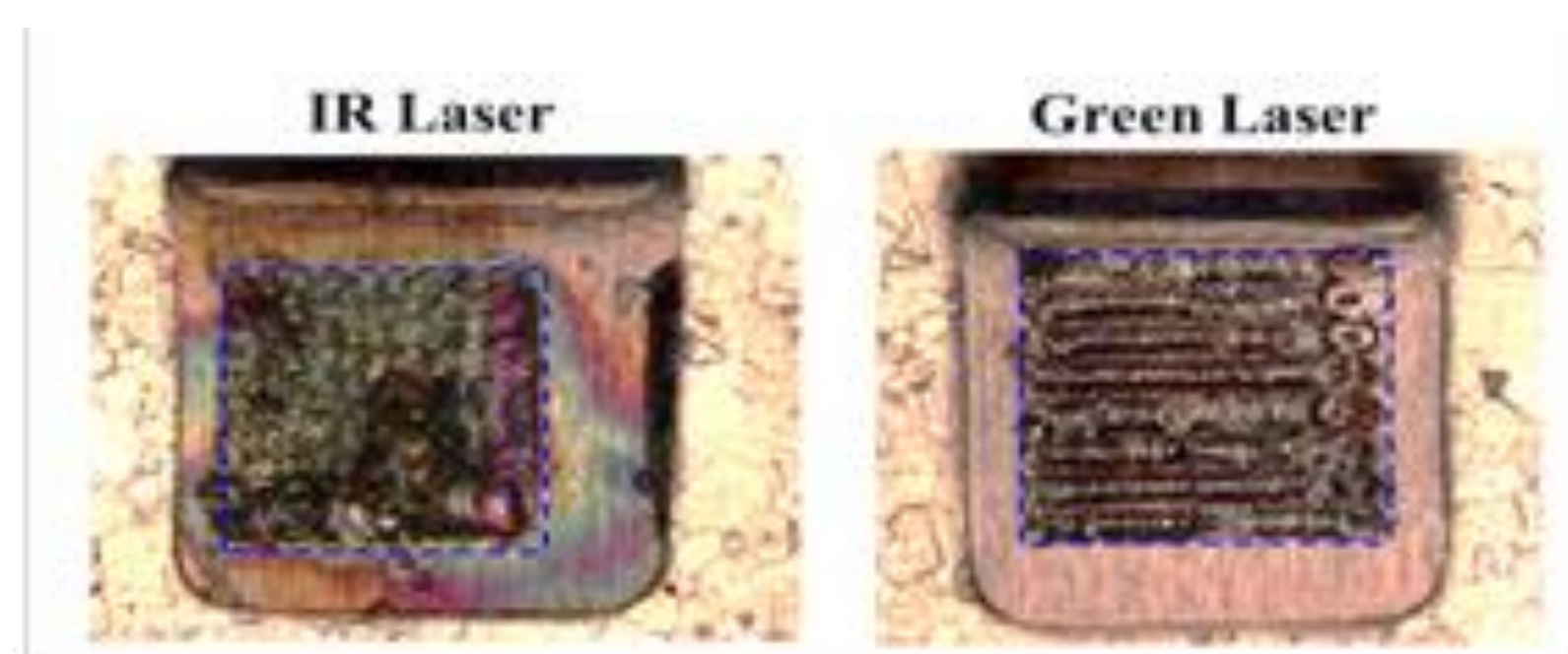


**Fig. 4:** IR vs. Green laser

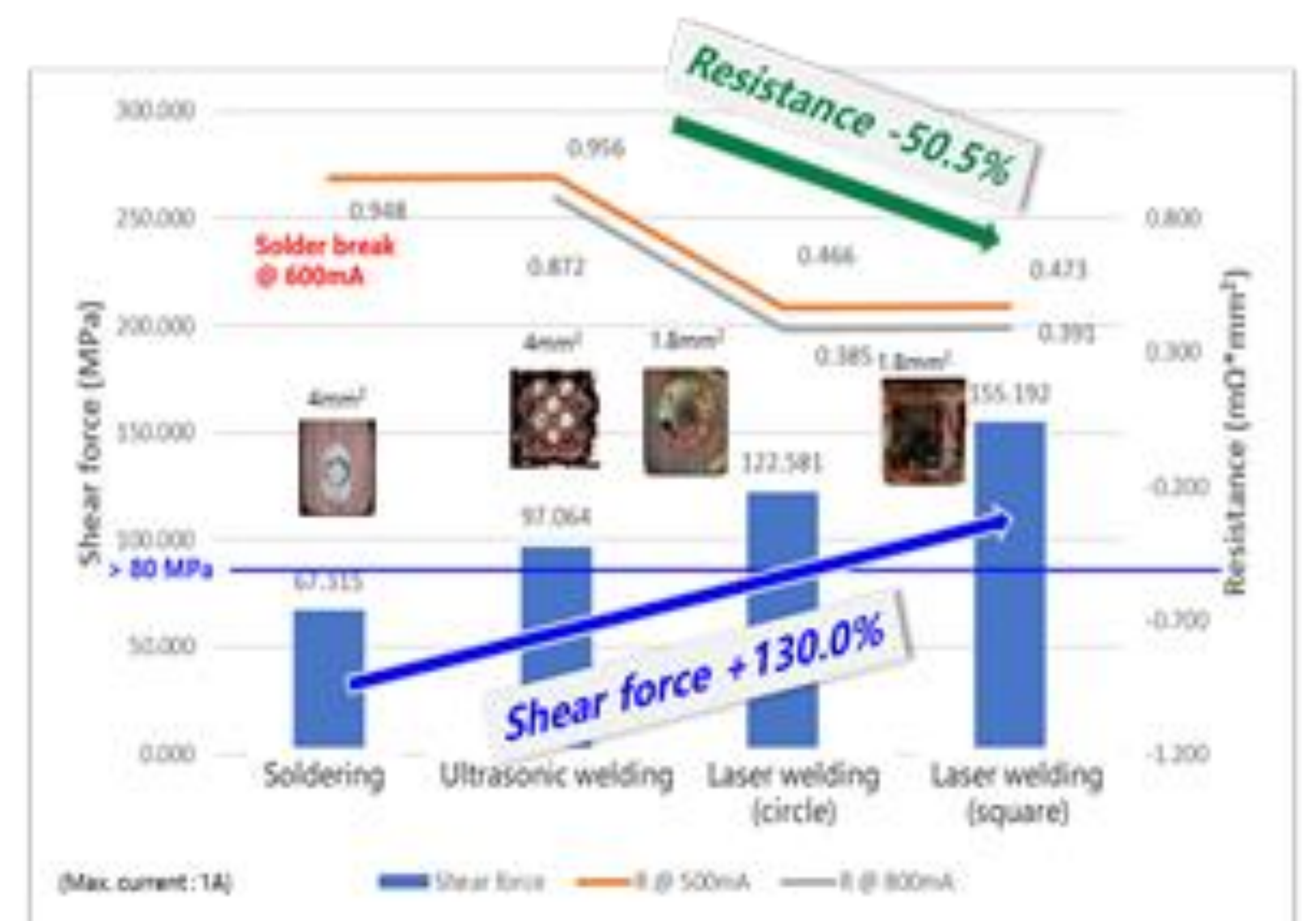


**Fig. 5:** Interconnections' electro-mechanical performance

After 1,000 TCT cycles ( $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$ ), laser-welded modules for xEV applications showed only minor, stable delamination. SEM confirmed intact critical interfaces, proving LW yields highly reliable interconnections. (refer to Fig.6~8)

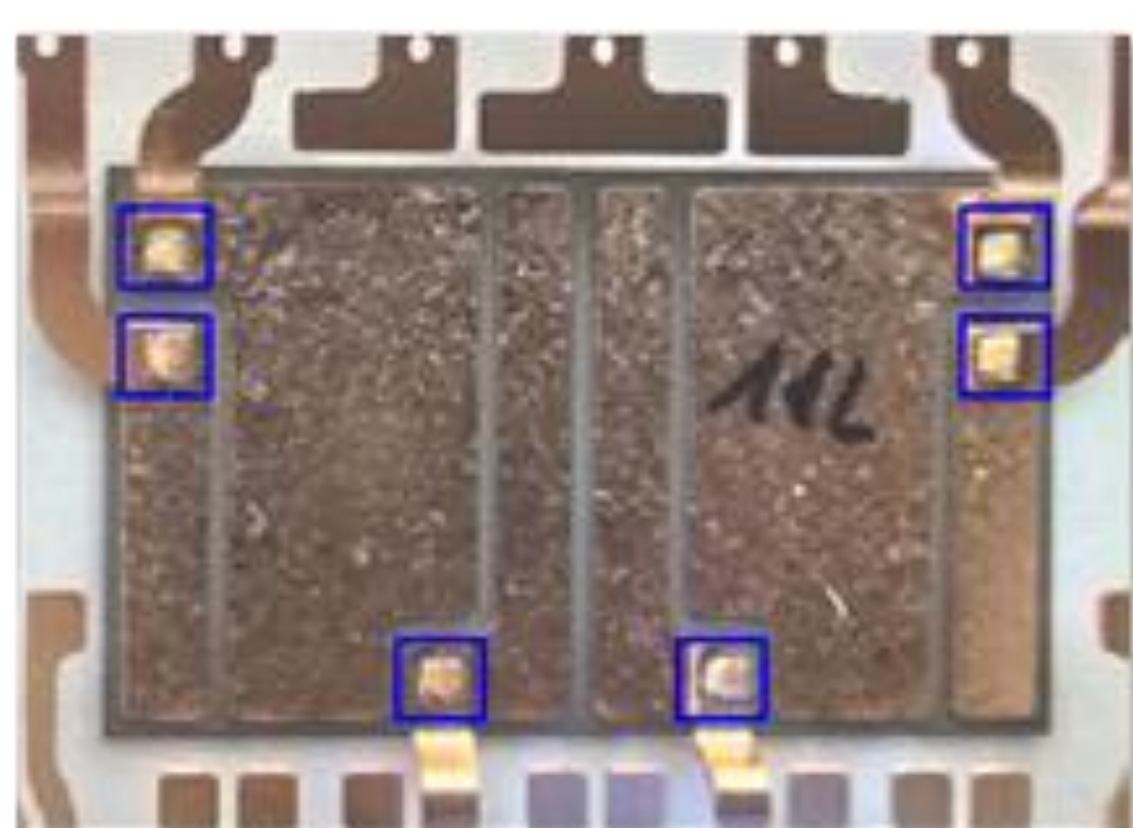


**Fig. 6:** Test Vehicle with 6 LW points (before molding)

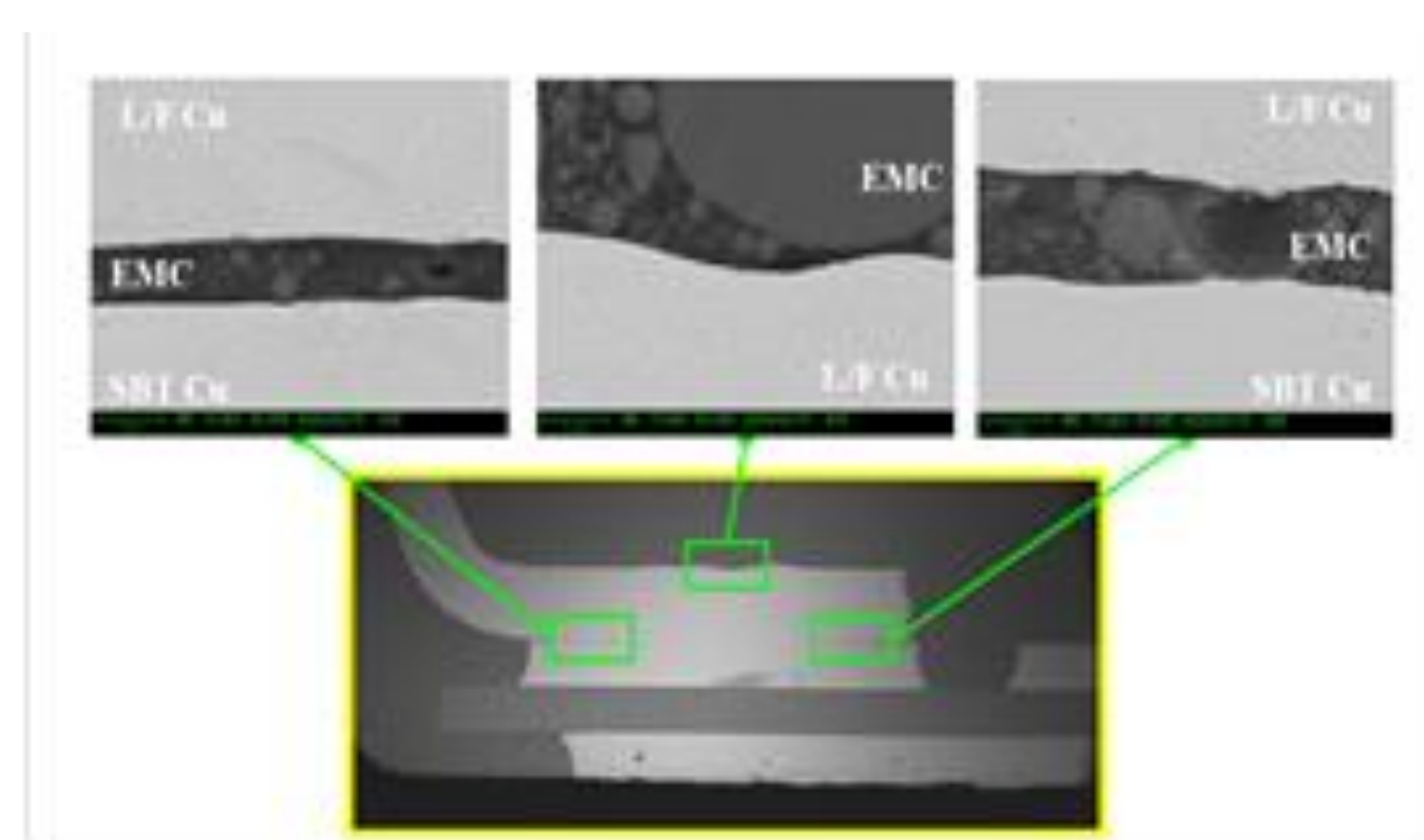


**Fig. 7:** After reliability under SEM: LW with IR laser

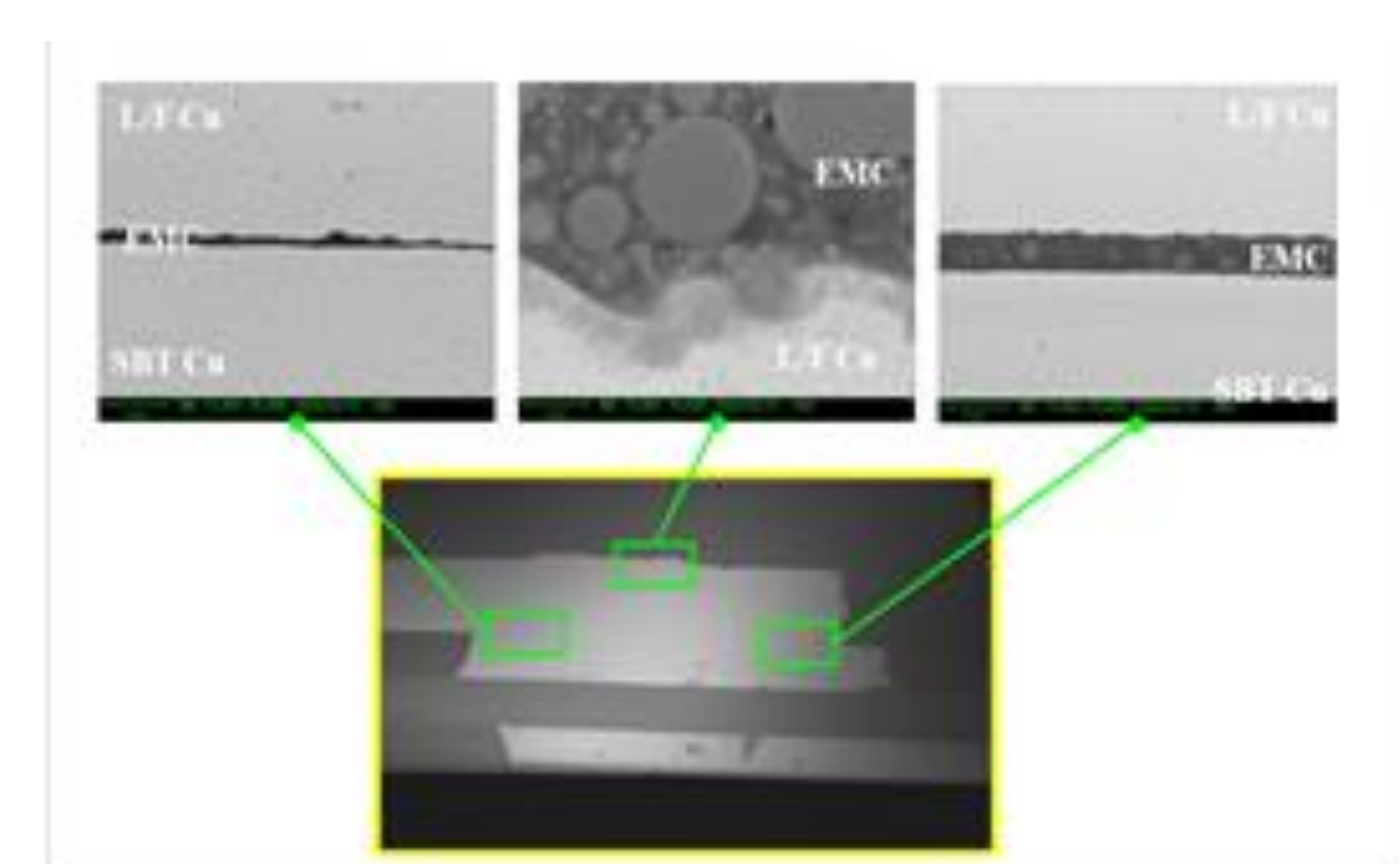


**Fig. 8:** After reliability under SEM: LW with Green laser

## CONCLUSION

Optimized green laser welding (LW) is essential for next-generation xEV and HPC power modules. Outperforming soldering and ultrasonic welding, LW delivers superior shear strength (155 MPa), halves contact resistance, and ensures robust thermal reliability, perfectly meeting the rigorous demands of advanced wide-bandgap semiconductor packaging.