Researchers measure electron emission to improve understanding of laser-based metal 3-D printing

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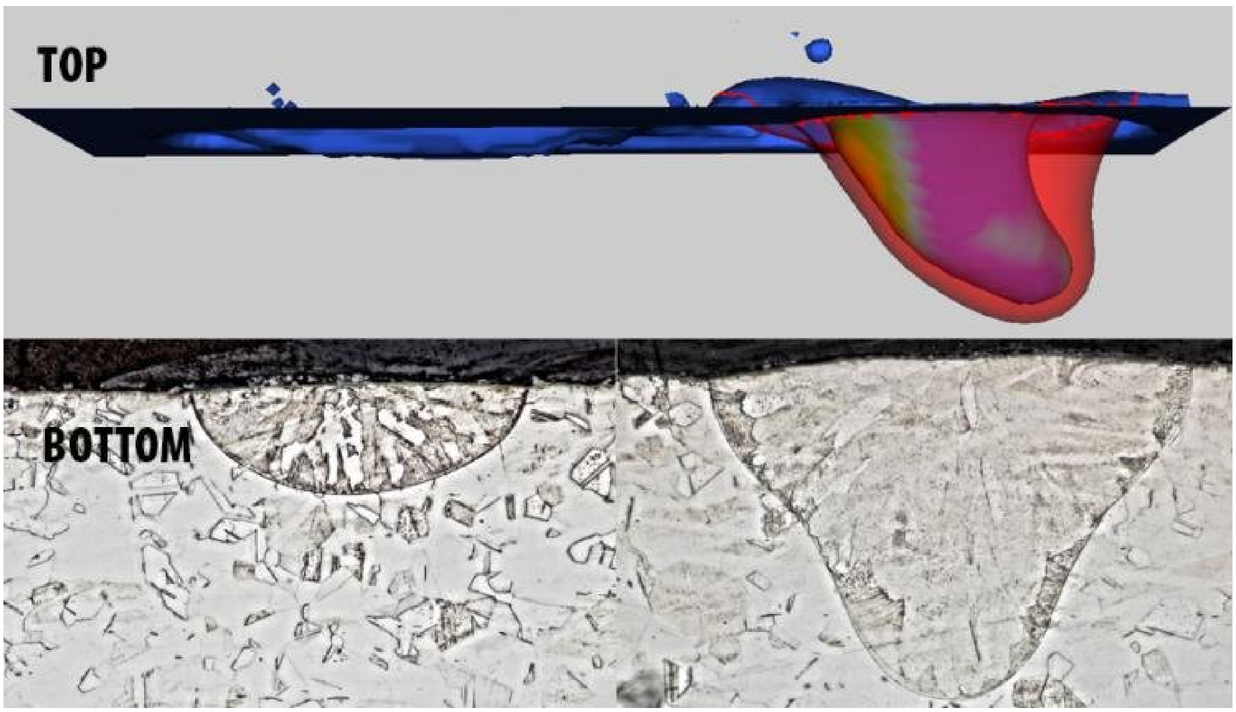

Researchers measured the emission of electrons from the surface of stainless steel under laser powder bed fusion (LPBF) conditions, demonstrating the potential for using thermionic emission signals to detect phenomena that can produce defects in parts and improve understanding of the LPBF process. The top image shows a multi-physics simulation of laser-induced melting of stainless steel, showing the electron emission signal primarily produced at the front of the surface depression. The bottom image depicts cross-sections of laser tracks produced in stainless steel. Monitoring of the thermionic emission can detect transition between conduction (left) and keyhole (right) mode welding regimes.

Credit: Aiden Martin/LLNL

Lawrence Livermore National Laboratory (LLNL) researchers have taken a promising step in improving the reliability of laser-based metal 3-D printing techniques by measuring the emission of electrons from the surface of stainless steel during laser processing.

Researchers collected thermionic emission signals from 316L stainless steel under laser powder bed fusion (LPBF) conditions using a custom, testbed system and a current preamplifier that measured the flow of electrons between the metal surface and the chamber. Then they used the generated thermionic emission to identify dynamics caused by laser-metal interactions. The journal *Communications Materials* published the work online on Nov. 27.

The team said the results illustrate the potential for thermionic emission sensing to detect laser-driven phenomena that can cause defects in parts, optimize build parameters and improve knowledge of the LPBF process while complementing existing diagnostic capabilities. Researchers said the ability to capture thermal emission of electrons will help advance basic understanding of the laser-material interaction dynamics involved in the LPBF process and support the broader technology maturation community in building confidence in parts created using the technique.

"Producing defect-free parts is a major hurdle for widespread commercial adoption of metal additive manufacturing (AM)," said principal investigator Aiden Martin. "LLNL researchers have been addressing this problem by developing processes and diagnostic tools for improving the reliability of metal AM. This new methodology complements these existing diagnostic tools to increase our understanding of the 3-D printing process. Our next steps are to expand this technology into a sensor operating on a full-scale LPBF system to increase confidence in the quality of built parts."

Researchers said while significant research has been done to understand and measure how parts are printed with LPBF through optical imaging, X-ray radiographs or measuring thermal or acoustic signal emissions, thermionic emission has been overlooked. But by observing and analyzing the electrons emitted during laser processing, Lab researchers demonstrated they could tie increases in thermionic emission to surface temperature and laser scanning conditions that cause pore formation and part defects.

Through experimental data and simulation, researchers reported the thermionic emission signal increased exponentially, and melt pool depth increased linearly, with local energy density, demonstrating the "critical dependence" of the metal's surface temperature on thermionic emissions and the utility of using thermionic signals as a way to optimize laser focus in LPBF.

"Electron emission in metal additive manufacturing has generally been overlooked by the community, and we were excited to observe its extreme sensitivity to process conditions," said first author and LLNL engineer Phil DePond.

The team's observations revealed that plasma formation during the LPBF process, which they previously ascribed to the ionization of vaporized metal by the laser beam, also could be caused by electrons ejecting from the metal surface into the argon gas atmosphere and interacting with the laser.

Researchers said the high sensitivity of thermionic emission to surface temperature and surface morphology allows them to determine the exact transition point between conduction and keyhole formation, which results in pore formation in parts. They concluded the results show thermionic signals can be used effectively with traditional LPBF data collection and processing methods, improve scientific knowledge of laser-material interactions and identify where defects might arise.

More broadly, the work "represents an important step toward establishing effective in situ monitoring capabilities that can accelerate qualification and certification of LPBF components," said co-author and Laser Material Interaction Science Group Leader Manyalibo "Ibo" Matthews.

More information: Philip J. DePond et al. Laser-metal interaction dynamics during additive manufacturing resolved by detection of thermally-induced electron emission, *Communications Materials* (2020). DOI: 10.1038/s43246-020-00094-y

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