Revolutionizing 3D printing through microwave technology

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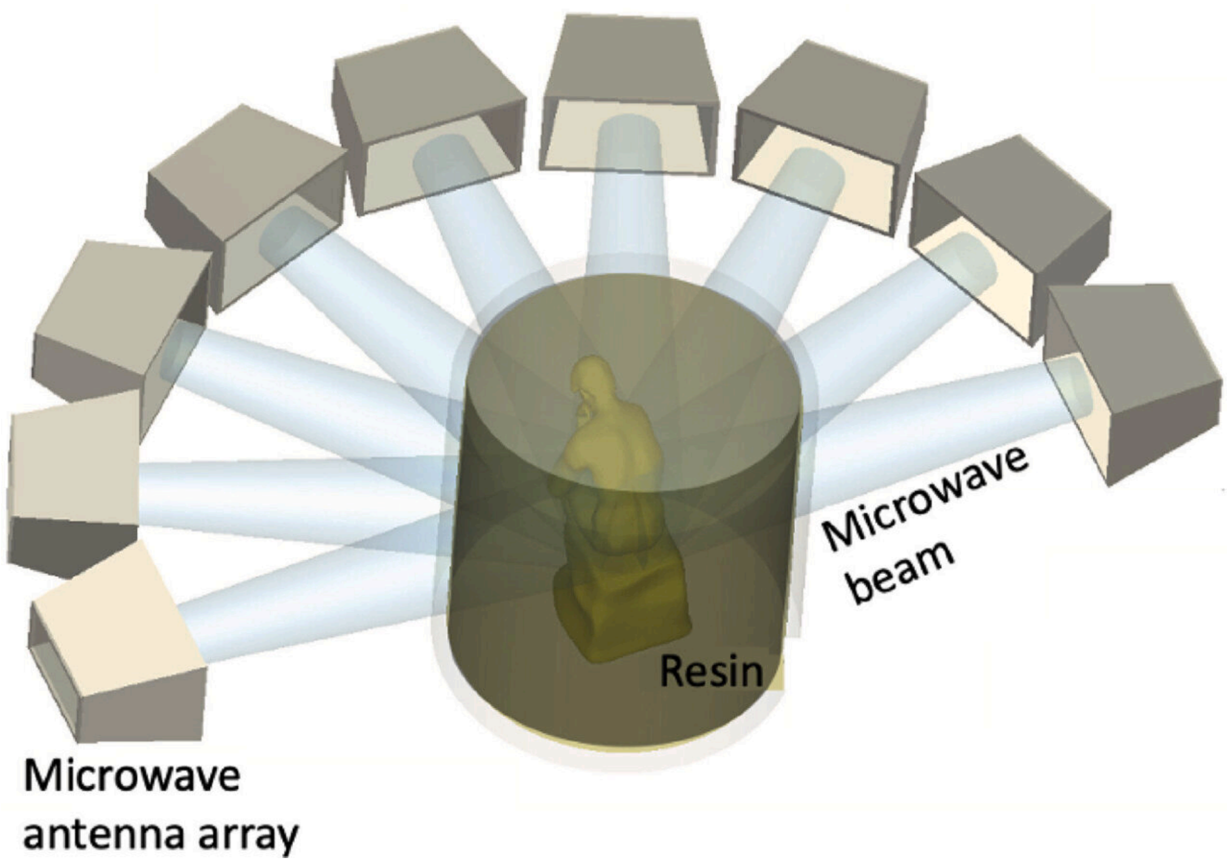

Proposed MVAM system. Superposition of beams from antenna array focus energy to arbitrary locations, enabling complex patterning. Credit: *Additive Manufacturing Letters* (2024). DOI: 10.1016/j.addlet.2024.100209

In the rapidly evolving world of 3D printing, the pursuit of faster, more efficient and versatile production methods is never-ending. Traditional 3D printing techniques, while groundbreaking, are often time-consuming and limited in the kinds of materials they can use as feedstock.

But, through a new process a Lawrence Livermore National Laboratory (LLNL) team is calling Microwave Volumetric Additive Manufacturing (MVAM), researchers have introduced an innovative new approach to 3D printing using microwave energy to cure materials, opening the door to a broader range of materials than ever before.

In a recent paper published in *Additive Manufacturing Letters*, LLNL researchers describe the potential of microwave energy to penetrate a wider range of materials compared to light-based volumetric additive manufacturing (VAM).

While VAM techniques like Computed Axial Lithography allow for rapid printing of complex 3D shapes in a single operation and eliminate the need for support structures, VAM relies on specific materials, primarily transparent and low-absorbing resins, which restricts the use of opaque or composite materials.

Compared to projected light, microwaves can reach deeper into materials, making them an ideal candidate for curing a variety of resins, including resins that are opaque or loaded with additives, researchers said. This capability could significantly enhance the versatility of 3D printing, allowing for the creation of more complex, functional and larger parts, according to LLNL research scientist Saptarshi Mukherjee, who co-led the paper with Lab materials chemist Johanna Schwartz.

"I think this is going to revolutionize the way people look at additive manufacturing," said Mukherjee, who specializes in applied electromagnetics. "If we think about a lot of applications—aerospace, automotive, nuclear industry—their geometries are simple, but they are large and they need rapid prototyping.

"One major impact [of MVAM] is if we can maintain a feedstock of materials surrounded with a microwave antenna array, we can now think about creating simple large geometries, as well as complicated large geometries, at scale using microwaves."

Co-author Maxim Shusteff, co-inventor of the original visible light-based CAL approach, said the ability to quickly produce parts with large geometries could be a game changer for additive manufacturing.

"Microwave volumetric AM opens up a new frontier in 3D printing by enabling the use of opaque and filled materials, which were previously challenging to work with," Shusteff said, "This can be a path toward large-format parts with enhanced material properties."

A breakthrough in curing technology

To explore the potential of microwave VAM, the research team at LLNL developed a multi-physics computational model of the microwave beams, designed to optimize power delivery and curing time and ensure better thermal control during the printing process. By simulating how microwaves interact with different materials, the team can predict how effectively they can cure various resins.

The researchers validated their model using a proof-of-concept experimental system and demonstrated the ability to cure a wide variety of materials, including both optically translucent and opaque epoxy resins.

The results were impressive: while existing microwave hardware operating at 40 watts could cure resins in about 2.5 minutes, the model suggested that curing times could be reduced to as little as six seconds at one-kilowatt power levels—about the same amount of energy as a standard microwave oven.

This capability could potentially speed up the production process and allow for the creation of larger parts, researchers said. The team found that their approach can print features ranging from a few millimeters to 20 millimeters, with the potential to scale up to meter-sized structures in the future.

The multi-physics model allows researchers to visualize how microwave energy propagates through materials and how it affects the curing process. By understanding properties of different materials, the team was able to fine-tune the microwave energy to achieve optimal results, researchers reported.

Co-principal investigator Schwartz, the team's chemistry lead, said that while traditional (optical) VAM is limited by the need for transparent, low-absorbing photoresins, with microwave VAM, "a whole new world of printing materials becomes possible."

"With have a unique opportunity to expand the definition of what is 'printable,' accessing chemistries previously not possible in light-based systems," Schwartz said. "This is a whole new printing space, and so our ongoing progress is just extremely exciting."

Mukherjee added that researchers could apply the same concepts used in optical VAM, but do so with "an array of antennas and beamforming algorithms" instead of a standard light projector.

"We are developing the full antenna array system with beamforming algorithms and we're specifically looking at ceramic materials because of their inaccessibility by conventional VAM and also because of their promise in various high-temperature, high-pressure kinds of environments," Mukherjee said.

Researchers said the implications of the work could extend far beyond the Laboratory. The ability to cure a wider range of materials quickly and efficiently could be transformative in industries such as aerospace, automotive and health care. For instance, manufacturers could create complex components with integrated functionalities, such as sensors or conductive pathways, all in a single printing process.

In addition, the potential for using opaque and composite materials means that products can be designed with enhanced properties, such as improved strength, thermal resistance or electrical conductivity. This versatility could lead to the development of entirely new products and applications that were previously unimaginable, according to the researchers.

As the team continues to refine their MVAM system, they envision a future where multi-antenna arrays can be used to further enhance the curing process and make manufacturing more efficient and capable of producing a wider array of materials at unprecedented speeds, pushing the boundaries of what's possible in AM.

But first, researchers will need to figure out how to make the process cheaper, and potentially spin the technology out to industry. Future work also aims to incorporate particle-scale effects into the model, further enhancing its predictive capabilities.

"High-power microwave devices are extremely expensive—a one-kilowatt pulsed microwave amplifier system could cost between $50,000 and $100,000," Mukherjee said.

"We are looking at how we can custom design or custom build some of these circuits or hardware by ourselves so that we can reduce a lot of cost and show that the overall concept works before big projects or outside external sponsors are willing to invest in this technology."

More information: Saptarshi Mukherjee et al, Towards microwave volumetric additive manufacturing: Generation of a computational multi-physics model for localized curing, *Additive Manufacturing Letters* (2024). DOI: 10.1016/j.addlet.2024.100209

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