Berkeley Sensor & Actuator Center

Multimaterial Nanoscale 3D Printing

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Staff/Level:	1 Graduate Researcher	Status:	Continuing
Sponsor(s):	Member Fees	Start Date:	May 2022

LONG RANGE GOALS

We propose a new multimaterial direct-write printing technique with projected sub-micron resolution. Inorganic nanoparticles (≈1-10nm) of common microfabrication materials are electrically charged, manipulated electromagnetically in vacuum with an ion trap, and shot toward a substrate where they deposit onto a part under construction, similar to PVD methods. To date, we have successfully demonstrated basic multimaterial deposition. Eventually, this ion printing technology could allow rapid prototyping of integrated circuits and MEMS.

BACKGROUND

R&D of new MEMS devices is hard because weeks to months are often required to fabricate a single prototype, and afterward, economical production requires very large volumes. We believe there is a need for low-lead-time, low-volume devices. Analogy with macroscopic 3D printing suggests a solution is a direct-write rapid prototyping method that sacrifices throughput for flexibility. Existing rapid prototyping tools are limited by resolution (inkjet minimum feature size is >10µm) or inability to pattern certain materials (two-photon lithography can usually only print photopolymers). In this project, we start with aerosol deposition (nanoparticles accelerated via gas flow), which is known to be able to print high density metals and ceramics but is limited to 10µm resolution, and we propose an electric field focusing technique to print with sub-micron feature sizes (<100nm may be feasible).

PRIOR RESEARCH RESULTS

- Engineered larger vacuum chamber and XY stage to assist in next research steps
- Proposed and simulated linear accelerator (linac) to uniformly accelerate nanoparticles

SPECIFIC RESEARCH RESULTS SINCE THE LAST RESEARCH REVIEW

- Demonstrated nanoparticle generation via laser ablation (instead of spark ablation)
- Demonstrated multimaterial printing with Cu, Ag, Au (conductive), Si on alumina

PROBLEMS TO BE ADDRESSED PRIOR TO THE NEXT RESEARCH REVIEW

- Lead researcher (Daniel Teal) is graduating
- Next steps include a better vacuum chamber to reduce oxidation and better UV lamps for photoelectric nanoparticle charging to implement electrostatic focusing

RESEARCH PLAN, MEASURABLE MILESTONES, AND GOALS

May 2022	Project began
Sep 2022	Created analytical models and ran computer simulations
Mar 2023	Initial tests of electrospray and sublimation nanoparticle sources (decided this was a dead end; began work on a spark ablation instead)
Jul 2023	Successful test of spark ablation nanoparticle source
Sep 2023	Demonstrated aerosol deposition of silicon and copper
Feb 2024	Proposed linac, engineered larger vacuum chamber for future experiments
Jul 2024	Refined linac theory, demonstrated laser nanoparticle source (spark source generated EMI), demonstrated printing with more materials (Cu, Ag, Au, Si, etc), conductive Au

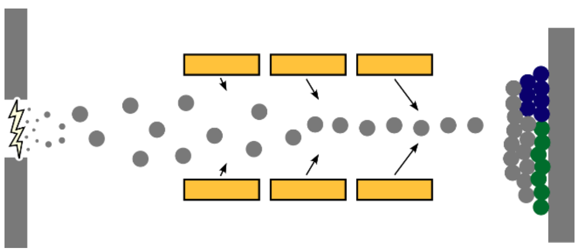

Fig. 1: Printer concept. Nanoparticles are produced by vaporizing material with a laser or spark then nucleating in an inert gas. They are optionally charged via photoelectric effect. Electrodes (specifically, a combination of segmented quadrupole ion trap and linac) will focus particles into a sub-micron-diameter beam. This impacts a substrate on an XY stage to print devices. Switching nanoparticle sources changes material.

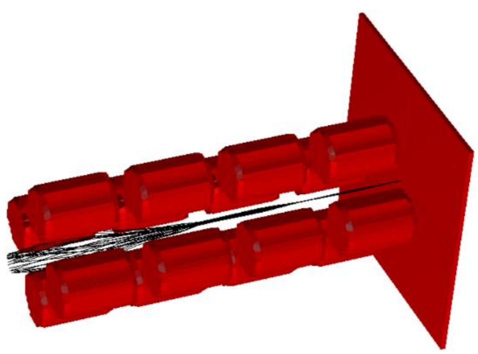

Fig. 2: A simulation of nanoparticle focusing and acceleration via SIMION, an industry standard ion optics software. Particles emitted from a realistically random source on the left are successfully focused into a tight beam before impact with the substrate on the right. The beam travel is about 100mm.

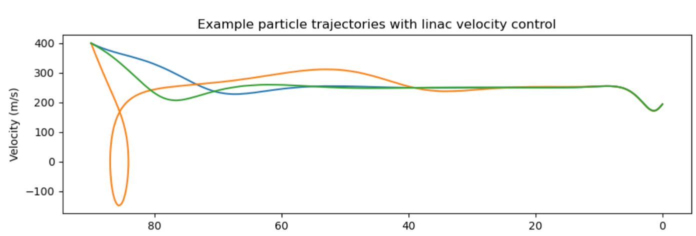

Fig. 3: A simulation similar to Fig. 2 in which a traveling wave at 250m/s is applied between electrodes in the direction of beam travel to form a linear accelerator (linac). The wave, plus air drag, results in particles asymptotically achieving the same 250m/s velocity before substrate impact despite variation in initial particle conditions.

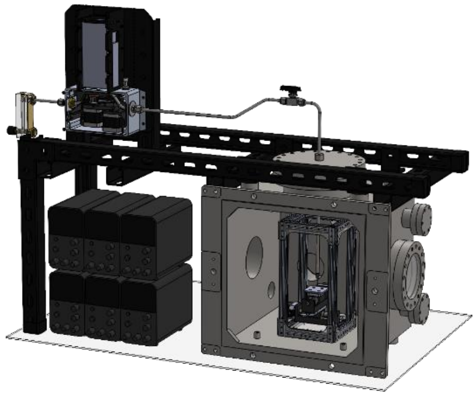

Fig. 4: cross-section render of current experimental apparatus. Gas flows in from the left, passes a material sample that a 1064nm pulsed diode laser vaporizes, then carries the resulting nanoparticles into a 2 Torr vacuum chamber. The nanoparticle + gas flow is focused with a nozzle onto a substrate with XY stage (note this is aerosol deposition, which already exists). We have also simulated the use of ion optics to further focus nanoparticles for deposition but need a better <250nm UV source for photoelectric nanoparticle charging in order to demonstrate this. This is very feasible in future work.

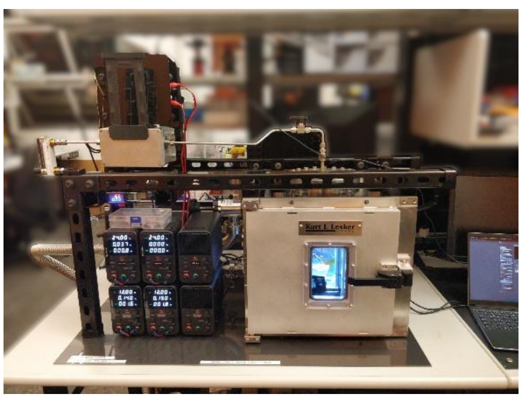

Fig. 5: Picture of experimental apparatus.

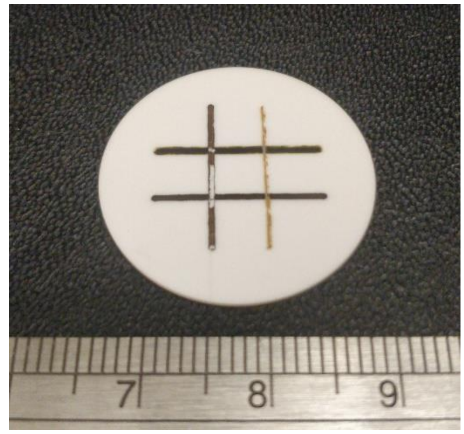

Fig. 6: copper (top horizontal), silver (bottom horizontal), gold (left vertical), and silicon (right vertical) lines printed on alumina. The gold is conductive and does not adhere well to alumina, as expected. Other materials are oxidized from ambient oxygen.

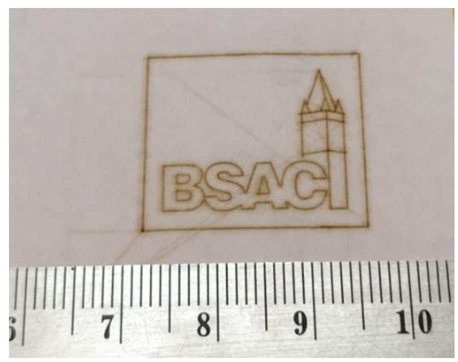

Fig. 7: The BSAC logo printed in copper on paper.