Additive Manufacturing for Microelectronics

IMAPS Italy

Abstracts

3D Printed Microelectronics & New Design Thinking

Rafael del Rey

Nano Dimension

The need for more complex but sustainable electronics makes electronic development an increasingly convoluted task.

New manufacturing tools and methods are thereby required to generate new sustainable proposals without resigning on complexity such as Additive Manufacturing of Electronics (AME).

Additive manufacturing of printed electronics is replacing traditional development processes in new ways by enabling complex geometries, embedding 3D-printed components and significantly shortening the development cycle.

Furthermore, AME enables embedding of passive and active components within a single package/board.

Nano Dimension uses a manufacturing process (inkjet printing) in which conductive silver nanoparticle ink and insulating ink are bonded and cured/sintered layer by layer, allowing new geometric freedom in 3D and thus a variety of novel applications (RF, IC staking, encapsulated sensors, unconventional system-in-package solutions) allowing them to include complex features such as curved vias, coaxial and waveguide transmission lines or truly twisted pair routings.

This presentation will showcase the latest developments of AME technology within Nano Dimension and how Nano Dimension foresees the future design of printed circuit boards, starting with the status quo on current PCB technologies, the generalities of the AME process, and the AME potential applying a new design thinking for RF applications, multilayer and complex high density interconnects, non-planar transmission lines, embedding & encapsulation of components, and electromechanical printed devices, finishing with ways to achieve it using current 2D ECAD tools along with 3D MCAD.

High-frequency Aluminum Nitride pMUT Probes Enclosed in a Miniaturized Architecture by Additive Manufacturing Technology

Vincenzo Mariano Mastronardia,b, Antonio Qualtierib, Enrico Bonid, Piero Tortolid, Roberto De Fazioa,c, Paolo Viscontia,b, Massimo De Vittorioa,b

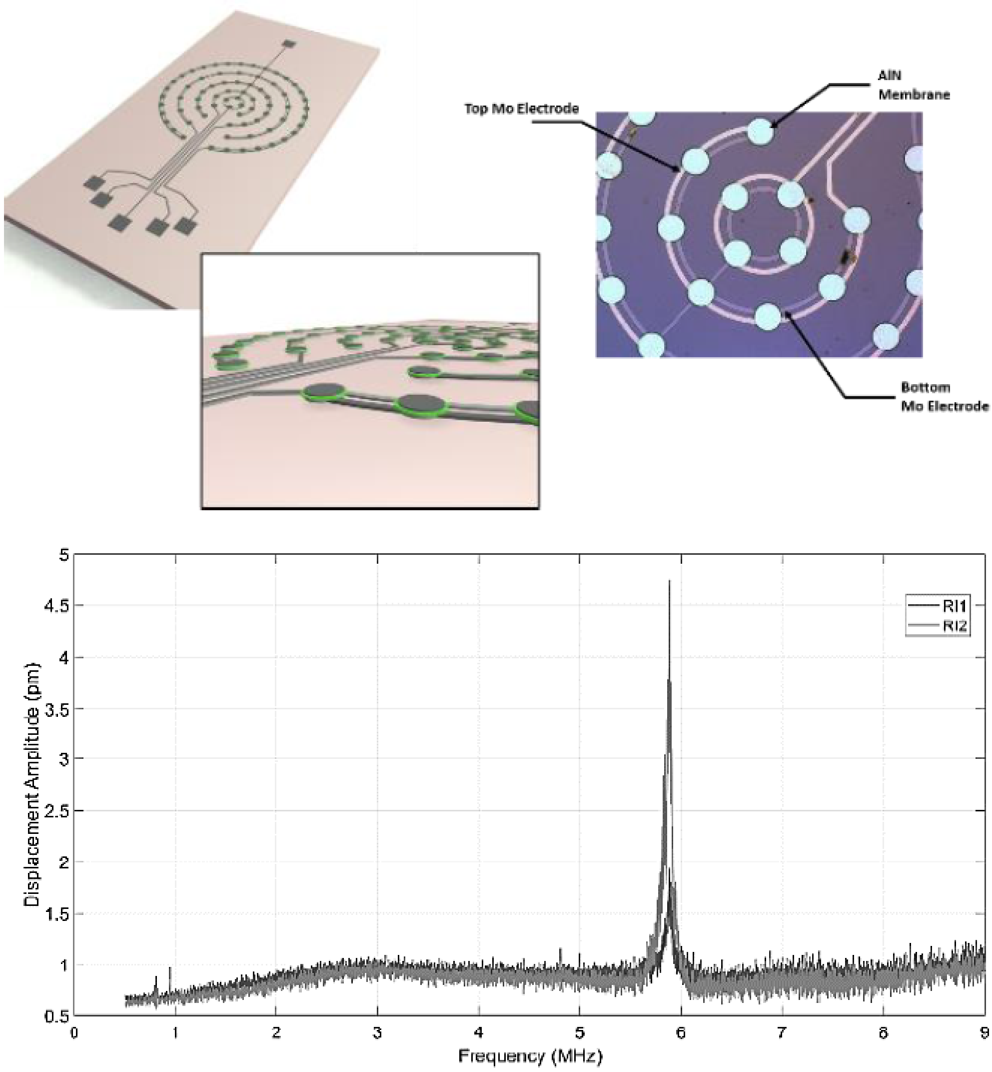
a Department of Innovation Engineering, University of Salento, 73100, Lecce, Italy
b Center for Biomolecular Nanotechnologies, Istituto Italiano di Tecnologia, 73010, Arnesano (LE), Italy
c Facultad de Ingeniería, Universidad Panamericana, Aguascalientes 20290, Mexico
d University of Florence, Dipartimento di Ingegneria dell'Informazione, 50121, Florence, Italy

e-mail: vincenzomariano.mastronardi@unisalento.it

Medical imaging applications frequently involve scanning human body tissues using high-frequency ultrasonic transducers (UTs, 2 – 15 MHz). In high-resolution imaging, micromachined ultrasonic transducers (MUT) have become a viable alternative to traditional piezo-ceramic devices [1] due to their compact size, inexpensive manufacturing process, and integration with standard CMOS technology and conventional circuitry. Indeed, they allow for reducing the device dimensions and enable a new level of functionality for sensing and imaging applications. Moreover, this makes them highly appealing for mass production. Circular, annular, and dome-shaped flexural membranes can be used to develop MUT, which can then be activated by different transduction mechanisms such as capacitive (cMUT) [2], [3] or piezoelectric (pMUT) [4]–[7]. More specifically, due to the substantial advancements in piezoelectric thin film technology and miniaturization of the architectures over recent years, pMUT probes have gained extensive development. Enhanced sensitivity, faster response times, and increased design flexibility are among the main advantages of pMUT. Despite these benefits, there are still some limitations in incapsulating small-size pMUT. In this context, Additive Manufacturing Electronics (AME) is an interesting technology with a high potential for directly integrating pMUT with standard electronic circuitry [8]–[12]. It enables fast custom-made prototyping, three-dimensional circuit boards, and small-series production.

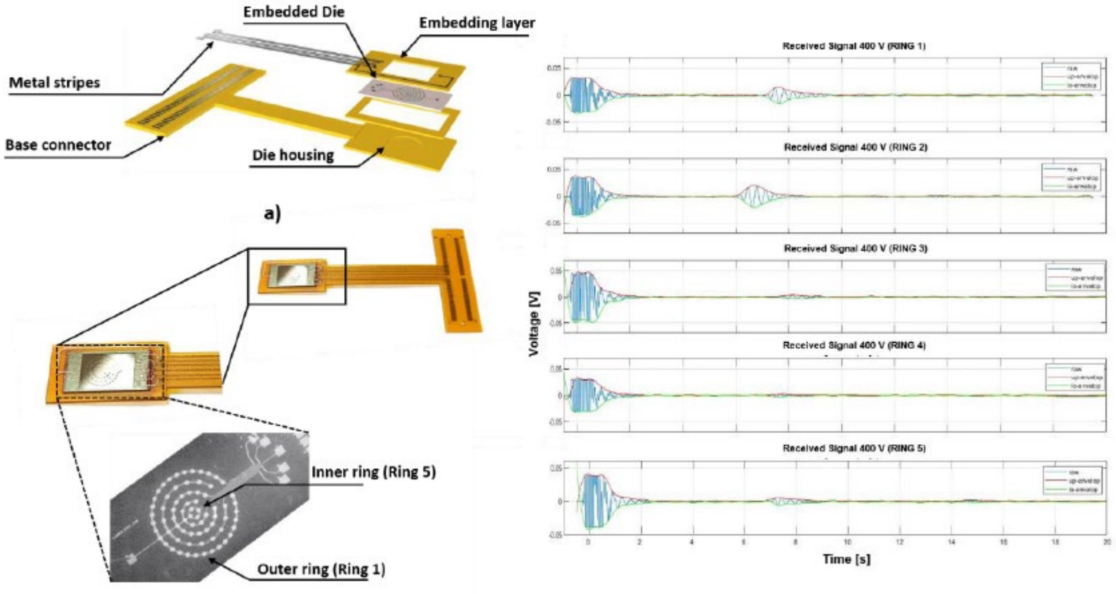
In this study, annular probes composed of circular-addressed 2-dimensional suspended Aluminum Nitride (AlN) pMUT array were fabricated. Silicon was used as the structural substrate for the UT probes. AlN-based disks (1 μm thick), embedded between two molybdenum electrodes (300 nm thick), were organized in annular arrays (as shown in Fig. 1a). The thickness of the suspended membranes (tm = 25 μm, including the AlN film and structural silicon) and their radius (rm = 100 μm) were accurately engineered and designed to operate at a central frequency of 6 MHz (Fig. 1b). The final size of the silicon die is 13 mm x 7 mm, including the 6 mm small probe.

The UTs' arrays were directly packaged and electrically connected using AME technology, which allowed the creation of complex, multilayered, high-performance electronic prototypes. The packaging was additively printed using Nano Dimension's DragonFly IV® system, whose manufacturing protocol was adequately optimized. AME technology enabled automated alignment of the probe with the built package and direct electrical connection to signal PADs. Moreover, it allows to avoid of standard bonding while simultaneously providing durable enclosing in a very thin board (500 μm) (Fig 2a - b). A pulser/receiver and a commercial immersion transducer (1 MHz bandwidth and 5 MHz nominal frequency) were used to analyze the transmitted ultrasound. Negative driving pulses (400 V amplitude, 1 kHz repetition frequency, 30 ns pulse duration) were used to drive each ring separately, while the probe, entirely isolated by parylene C covering, was immersed in liquid. A 5-ring annular array probe was characterized; it comprises 72 AlN membranes arranged in five rings (31, 15, 15, 7, and 4 transducers from the outer to the inner ring). The immersion transducer detected the acoustic wave generated by each ring and provided an output signal that was collected by the oscilloscope. Figure 2c shows the emitted signals from the five rings (the upper and lower envelope – red and green traces, respectively – are also reported) acquired by the commercial transducer. According to preliminary results, the AlN-based probes can produce acoustic waves within a bandwidth of 1 MHz at a test distance of about 1 cm. Integrating high-frequency pMUT probes and miniaturized architecture by using additive manufacturing technology is a promising approach for developing advanced sensors for various ultrasound applications.



a) b)

Figure 1: a) annular probe consisting of AlN – based membranes arranged along five circular rings; b) frequency spectrum of the single membrane showing the operating frequency centered at ≈ 6 MHz.



b) c)

Figure 2: a) 3-D design of the package; b) final probe encapsulated into additively printed packaging; c) transmission measurement in the time domain for the 1st mode of resonance when the pMUT is immersed in liquid (Ring1 is the outer and most populated ring, Ring5 is the inner).

[1] A. S, K. Krishnan, and M. Arora, “Review of pMUTs for medical imaging: towards high frequency arrays,” *Biomed. Phys. Eng. Express*, vol. 9, no. 2, p. 022001, Jan. 2023, doi: 10.1088/2057-1976/acaab2.
[2] K. Brenner, A. S. Ergun, K. Firouzi, M. F. Rasmussen, Q. Stedman, and B. (Pierre) Khuri–Yakub, “Advances in Capacitive Micromachined Ultrasonic Transducers,” *Micromachines*, vol. 10, no. 2, Art. no. 2, Feb. 2019, doi: 10.3390/mi10020152.
[3] C. D. Gerardo, E. Cretu, and R. Rohling, “Fabrication and testing of polymer-based capacitive micromachined ultrasound transducers for medical imaging,” *Microsyst Nanoeng*, vol. 4, no. 1, Art. no. 1, Aug. 2018, doi: 10.1038/s41378-018-0022-5.
[4] S. Pala and L. Lin, “Piezoelectric Micromachined Ultrasonic Transducers (pMUT) with Free Boundary,” in *2020 IEEE International Ultrasonics Symposium (IUS)*, Sep. 2020, pp. 1–4. doi: 10.1109/IUS46767.2020.9251628.
[5] Y. Qiu *et al.*, “Piezoelectric Micromachined Ultrasound Transducer (PMUT) Arrays for Integrated Sensing, Actuation and Imaging,” *Sensors*, vol. 15, no. 4, Art. no. 4, Apr. 2015, doi: 10.3390/s150408020.
[6] T. Liu *et al.*, “Flexible Thin-Film PZT Ultrasonic Transducers on Polyimide Substrates,” *Sensors*, vol. 21, no. 3, Art. no. 3, Jan. 2021, doi: 10.3390/s21031014.
[7] V. M. Mastronardi, F. Guido, M. Amato, M. De Vittorio, and S. Petroni, “Piezoelectric ultrasonic transducer based on flexible AlN,” *Microelectronic Engineering*, vol. 121, pp. 59–63, Jun. 2014, doi: 10.1016/j.mee.2014.03.034.
[8] F. Hemmelgarn, P. Ehlert, T. Mager, C. Jürgenhake, R. Dumitrescu, and A. Springer, “Evaluation of different additive manufacturing technologies for MIDs in the context of smart sensor systems for retrofit applications,” in *2021 14th International Congress Molded Interconnect Devices (MID)*, Feb. 2021, pp. 1–8. doi: 10.1109/MID50463.2021.9361628.
[9] G. Aspar *et al.*, “3D Printing as a New Packaging Approach for MEMS and Electronic Devices,” in *2017 IEEE 67th Electronic Components and Technology Conference (ECTC)*, May 2017, pp. 1071–1079. doi: 10.1109/ECTC.2017.119.
[10] K. Schmidt, B. Polzinger, M. Runtze, and A. Zimmermann, “Embedding and Contacting of Electrical Components for Hybrid Additive Manufacturing,” *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 12, no. 8, pp. 1401–1409, Aug. 2022, doi: 10.1109/TCPMT.2022.3195967.
[11] Z. Zhang and X. Yuan, “Applications and Future of Automated and Additive Manufacturing for Power Electronics Components and Converters,” *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 10, no. 4, pp. 4509–4525, Aug. 2022, doi: 10.1109/JESTPE.2021.3135285.
[12] G. Varzaru, M. Savu, B. Mihailescu, C. Ionescu, and M. Branzei, “Contributions to an additive method for manufacturing solderless assembly for electronics,” *J. Phys.: Conf. Ser.*, vol. 2339, no. 1, p. 012029, Sep. 2022, doi: 10.1088/1742-6596/2339/1/012029.

An Innovative Contactless Technology for High Resolution, High Speed, conductive & di-electric materials Deposition

Stéphane Etienne, Michael Zenou

Keyword: new equipment, copper deposition, dielectric materials printing, laser assisted deposition, advanced manufacturing, additive manufacturing, eco friendly

Conductive materials are being deposited at tighter and tighter resolutions. Various solutions have been proposed, but there is always a trade off somewhere. The tighter resolution can come at expense of custom materials, such as in inkjet, or speed, such as in dispensing. Ideally, we would have a liquid dispensing solution that had the throughput of the traditional analog solutions, such as screen printing, with the accuracy and flexibility of traditional digital solutions, such as jetting and needle dispensing.

With Continuous Laser Assisted Deposition (C.L.A.D.) there is no longer any trade off between materials and other parameters. This contact-less technology has no nozzle and no mesh. It can deposit drops from materials above 300,000 cPs (300Pa.s) at high speed and high resolution. The high viscosity window allows standard certified maaterials to be used from 300 cps up to ½ Million, without any reformulation.

This laser assisted deposition technology can be applied to several applications, but in this paper we will focus on copper and di-electric deposition. In addition to those, most other materials can be printed too, up to very high viscosities. This includes conductive materials, polymers, ceramics and silicone. The C.L.A.D. solution allows up to 5 different materials to be printed.

This multi material capability associated to embedded post processing such as curing (Heat/UV), sintering and ablation offer a unique capability to build multi-functional 3D structures. Providing a flexibility advantage and an industry matching expected productivity pace as well as major sustainability advantage vs existing technologies.

In the C.L.A.D. technology, a material, evenly coated on a transparent carrier film, passes under a laser. The laser applies a short burst of energy to it. This releases perfectly consistent drops of material onto the substrate below. The material drops can then be sintered or cured inline, in the same machine. Minimum resolutions are higher than currently achievable resolutions. Multiple component sizes can be handled, as well as component heights. Very high thickness to diameter rations can be achieved, sometimes by multiple passes.

With these multiple benefits, the technology has been widely recognized by industry as well as investors.

High-Performance Organic Electrochemical Transistors Manufactured with Micro-Dispensing

Fabrizio Torricelli

Department of Information Engineering, University of Brescia, via Branze 38, 25123 Brescia,
Italy

e-mail: fabrizio.torricelli@unibs.it

Organic electrochemical transistors (OECTs) rely on volumetric ion-modulation of the electronic current to provide low-voltage operation, large signal amplification, and enhanced sensing capabilities. The majority of current OECT technologies require multistep photolithographic microfabrication methods on glass or plastic substrates, which do not provide an ideal path toward ultralow cost ubiquitous and sustainable electronics and bioelectronics. At the same time, the development of advanced bioelectronic circuits combining bio-detection, amplification, and local processing functionalities urgently demand for OECT technology platforms with a monolithic integration of high-performance iontronic circuits and sensors. The talk will introduce fully printed mask-less OECTs fabricated with micro-dispensing technique. The dispensing method enables depositing both high- and low- viscosity OECT materials. Fully printed OECT unipolar inverter circuits and current-driven sensors for ion detection and real-time monitoring are integrated on rigid glass as well as on flexible biodegradable and compostable substrates. These universal building blocks manufactured with mass-scale micro-dispensing method can open opportunities for next-generation high performance and sustainable electronics and bioelectronics.

LIFT (Laser Induced Forward Transfer) copper pattern deposition for leadframe customization

Guendalina Catalano

ST microelectronics

e-mail: guendalina.catalano@st.com, mobile: +39 3386064229

In recent years, developments of biomedical, biomedicine and miniaturized devices entailed demand to have higher-precision and high-quality devices, so additive manufacturing technologies became a high focusing topic in research field. Laser Induced Forward Transfer technology is a direct write technique that is explored in biomedical application as DNA deposition [1] but thanks to the developing and improvement machines and materials can be promising also for microelectronics applications in terms of layout customization and new packaging concept developing. The aim of this work is to use Laser Induced Forward Transfer (LIFT) technologies for copper paste printing on Cu alloy leadframes for fast prototyping of new packaging layout. UV laser source coupled with automated paste dispenser and drying system are used to explore feasibility of 3D deposition. Different parameters are explored to reach high quality deposition of 95um Cu paste material and multilayer material with 95 um Cu paste plus 3um of Ag paste on top. Visual inspection with optical microscope, SEM analyses method on cross sections are performed to evaluate the geometry and the quality of deposition in terms of defectivity, as voids and cracks.

Reference

[1] *Laser surface structuring of ceramics, metals and polymers for biomedical applications: A review*, Shukla et all, Laser surface modification of Biomaterials, 2016

Scalable 3D Printed Electronics - High Volume to “Fully Additive”.

Martin Hedges

Managing Director, Neotech AMT

This presentation will review the state-of-the-art related to the production of 3D mechatronic systems using Additive Manufacturing (AM) and review developments for scaling the processes through all stages, from one off prototyping to high volume manufacture.

Reconfigurable arrays of structural and electronics printing, pre- and post processing techniques are combined with SMD technologies to enable digitally driven 3D electronics manufacturing. The resultant flexible process chains can be easily reconfigured to cope with rapid changes in product type whilst retaining the ability to be scaled through to high volume manufacture. Selection of the most appropriate print, pre- and post-processing methods with the subsequent effect on process speed and cost will be discussed.

A brief review of current applications, spanning 3D electronic circuits, antenna, sensor and heater patterns will be conducted along with an update on the progression to First Time Right manufacture of complex devices.

Short bio

“Graduated BSc (Materials Science) from the University of Manchester (UK) in 1987. Completed a PhD in Materials Science in 1990 from UMIST (UK).

Martin founded Neotech in Nuremberg in 2001 to develop additive manufacturing processes with a focus on Printed Electronics. Since 2009 the company has been pioneering the development of 3D Printed Electronics.”

Inkjet-printed polymeric dampers for MEMS application

Prisca Viviani[a], Martina Scolari[b], Ilaria Gelmi[b], Laura Castoldi[b] and Luca Magagnin[a]

[a] Dipartimento di Chimica, Materiali e Ingegneria Chimica "Giulio Natta", Politecnico di Milano, Via Luigi Mancinelli 7, 20131 Milan, Italy
[b] STMicroelectronics, Agrate Brianza 20864, Monza and Brianza, Italy

Email: luca.magagnin@polimi.it, prisca.viviani@polimi.it

Over years, additive manufacturing has gained growing interest and attention in applications where customization and cost-effectiveness are strategic features. In this frame, Ink-jet printing (IJP) has emerged as a potential process to be flanked by traditional microelectronics material deposition method, where less exigent restraints on resolutions are required. However, high resolution in the micrometric range can be achieved, making this technique attractive for microfabrication. Indeed, many devices feature microfabricated parts, as Micro-electro-mechanical systems (MEMS). Compared to more traditional surface patterning techniques, IJP is a contact-less, mask-less droplet-based technique able to deposit functional materials onto specific substrates. The possibility to finely control the thickness, by tuning the number of printed layers, combined with minimum material waste reveal the great versatility of this fabrication technique. However, major challenges of IJP are found on two levels. One is the long-term cartridges durability, as nozzle clogging is prone to occur. On the other hand, IJP requires precise ink rheological properties to guarantee flow under the application of a shear stress: low viscosity (i.e. 2-20 cP) and surface tension (i.e. 25.50 mN m^{-1}) [1,2].

IJP is also considered to be a key technology regarding polymers deposition. In particular, polymers are optimal candidate materials for vibration damping applications. Vibrations often represent a problem due to undesired motions and stresses, that can lead to fatigue, failure, degradation and reliability loss for a wide range of structures in microelectronics. As MEMS devices consist of mechanical parts, they are prone to experience harsh undesired vibrations too. There are two material classes for vibration control mechanism: active and passive damping. The most common passive damping material are Viscoelastic materials (VEMs), combining properties of elastic and viscous materials, where damping occurs by energy dissipation due to friction among oligomers chains under cyclic deformation. VEMs may be used as discrete dampers, absorbers or the surface of the structure can be fully or partially covered. As a matter of fact, a common viscoelastic treatment to control vibrations in a structure is the Free-layer damping (FLD) approach. The damping material is deposited on the structure surface, creating a damping layer. When the structure is deflected, vibrations are damped because of the energy dissipated following of the compression/extension of the damping material [3,4].

The aim of this work is to propose a simple VEM deposition through IJP on top of a spring in the MEMS device, exploiting the FLD approach. First, an extensive material selection has been performed to individuate an adequate polymeric material, with low elastic modulus that would not alter spring properties. The characterization of the optimized ink in terms of physical properties, to understand ink printability through considerations regarding the Ohnesorge diagram, will be presented. A jetting characterization will be also presented, evaluating the printability assessment as a function of the ink droplet speed. Printed pattern characterization will be discussed either in terms of surface profilometry, microscopy and vibration damping ability.

[1] R. Bernasconi, M. C. Angeli, F. Mantica, D. Carniani, L. Magagnin, *Polymer* 2019, *185*, 121933.
[2] E. P. Furlani, in *Fundamentals of Inkjet Printing*, John Wiley & Sons, Ltd, 2015, pp. 13–56.
[3] N. Choudhary, D. Kaur, *J Nanosci Nanotechnol* 2015, *15*, 1907.
[4] R. Singh, A. Ghosh, R. Kant, M. Asfar, B. Bhattacharya, P. Panigrahi, S. Bhattacharya, *Journal of Microelectromechanical Systems* 2013, *22*, 695.

A new dawn for electrohydrodynamic inkjet printing as an industrially relevant technology

Patrick Galliker

Scrona AG

Electrohydrodynamic (EHD) Printing has long be known as a potentially superior printing technology compared to conventional inkjet. Back in the 80's, EHD was explored for graphical applications by major players but has long since been abandoned. Beginning of the century, new activities have emerged mainly in relation to emerging industrial applications like printed electronics. The problems that keep the technology from becoming industrially relevant remain the same though. EHD printheads are not manufacturable with large nozzles counts, show intense cross-talk and require high voltages to be operated.

For the first time, an EHD printhead has been created that eliminates all these problems at once. Scrona's new MEMS-based EHD printheads contain nozzles at a density that can be more than five times higher than that of modern piezo-driven inkjet heads and they can be individually operated with ~60V which makes them compatible with massively scaled driving electronics. The cross-talk between individually operated, closely spaced nozzles is essentially negligible. This finally paths the way to exploit EHD printing as an industrially relevant technology.

Reaching silicon based MEMS sensors and actuators performances with 3D printing technologies

Stefano Stassi

Dipartimento di Scienza e Tecnologia Applicata, Politecnico di Torino

The sensor and actuator miniaturization obtained with MEMS an NEMS technologies offers the possibility to reach an unprecedented resolution in sensitivity and displacement. These very high detection resolutions are related to the combination of two factors: a small device mass and a high structure rigidity. The main drawback of MEMS is represented by the highly complex, multi-steps, and expensive fabrication processes. Several alternatives fabrication processes have been exploited, but they are still limited to large dimension and poor sensitivity and resolution. Here we report the fabrication of rigid MEMS and NEMS sensors and actuators with high sensing and displacement performances by a 3D printing approach. After a thermal step, we reach complex geometry printed devices composed of ceramic structures with high Young's modulus and low damping showing performances in line with silicon-based MEMS devices. We demonstrate the possibility of rapid fabrication of NEMS resonators for mass sensing and piezoelectric MEMS sensors and actuators that present an effective alternative to semiconducting devices.

Additive Manufacturing for Ultra-fine Resolution of Micro and Nanoscale Components and Interconnects for Advanced Packaging

Ahmed Busnaina

CTO Nano OPS, Inc., Burlington, MA

Website: www.nano-ops.net

The new ultrafine resolution requirements for heterogeneous integration have moved many advanced packaging applications to foundries instead of the traditional packaging industry. This led to a much higher cost that made the most advanced packaging applications out of reach for many small companies. In this paper, we present an additive high-throughput manufacturing solution that can enable low-cost manufacturing of trace, interconnect, passive and active components at the micro and nanoscale. It allows the required passives and active components to be manufactured along with the trace such that the only added discrete packaged components are microcontrollers, memory, or other chips. This technology is estimated to reduce cost by 10-100 times compared to conventional semiconductor manufacturing. It is enabled by directed assembly-based of suspended nanoparticles at room temperature and pressure and manufacture devices 1000 faster and 1000 smaller structures than inkjet-based or 3D printing. The process is scalable, environmentally sustainable, and enables precise and repeatable manufacturing using various materials at a high rate. This allows the printing of passive and active components monolithically on an interposer platform such that the total footprint can be within a few mm of the original IC footprint. The presentation will show the electrical and materials characteristics of capacitors, resistors, and transistors made using a fully additive process down to the submicron scale without using etching, vacuum, or chemical reactions.

---

2 photon lithography and ultra-thin films for plastic micro-electronics manufacturing and assembly

Virgilio Mattoli

Micro Electro-Mechanical Systems (MEMS) produced a great impact in the last twenty years on different market areas, due to countless technological applications. The performances of these systems rely on both the design and the intrinsic properties of the constituent materials, that have to be processed with sub-micron resolution, high precision and reproducibility. Two photon lithography (2PL), could be in the future a key technology toward the direct fabrication of MEMS devices, due the capability of directly producing outstanding three-dimensional structures with nanoscale features. The key aspect toward this objective will be the availability of functional and high performance materials compatible with 2PP process [1]. In this talk I'll present the perspectives, the requirements and the challenges of this approach, focusing on recent results of our group in term of MEMS fabrication and integration in the framework of the EU funded project 5D NanoPrinting [2]. In particular, the fabrication of integrated conformal metal paths by self-shadowing approach & conformal lift-off, the integration with silicon electronics and the ubiquitous transfer of 2PP microstructures will be presented in details. More general application of discussed technologies to the new emerging and exciting field of soft electronics (targeting seamless integration of electronics components and devices into non-rigid non-planar complex surfaces and object) will be also presented [3-5].

[1] M.Carlotti and V. Mattoli, Small, 15 (2019) 1902687

[2] https://5dnanoprinting.eu

[3] L. Ferrari *et al.*Advanced Science, 5 (2018) 1700771

[4] S. Taccola *et al.* MDPI Sensors, 21 (2021) 1197

[5] F. A. Viola *et al.*, Nature Communication, 12 (2021) 5842

Short bio

Virgilio Mattoli received his Laurea degree in chemistry (with honours) from the University of Pisa and the Diploma in Chemistry from the Scuola Normale Superiore of Pisa in 2000. In 2005 he received his PhD in bio-engineering (with honours) from Scuola Superiore Sant'Anna, with a thesis focused on the control and integration of miniaturized devices for environmental application. In summer 2004 he was visiting researcher at the University of Stanford, Center for Design Research, where he focused his activity on sensors and controls modules for biomimetic robotics applications. In 2005 and 2008 he was a short term visiting researcher at Waseda University (Tokyo, Japan) working on a bio-inspired mini-robot and on development of ultra-conformable polymeric films. From June 2008 to October 2009 he obtained a temporary position of Assistant Professor of bioengineer engineering at the Scuola Superiore Sant'Anna (SSSA). From November 2009 to July 2015, he has been a Team Leader of the Smart Materials Platform in the Center for Micro-BioRobotics of the Italian Institute of Technology (IIT). In August 2015, he obtained a permanent position as Researcher Technologist at the same center. His main research interests include: *smart nano- and bio-inspired materials, micro/nano-fabrication, soft/tattoo electronics, sensors, and biorobotics*. He is currently involved in several research projects on these topics, including the EU FET Project 5D NanoPrinting of which he is the coordinator. He is author or co-author of more than hundred seventy articles on international journals, of more about forty invited talks, and of several conferences communications, proceedings and deposited patents.

High Resolution Printing and Wide Area Coating Enabled by Aerosol Jet for Sensors and Electronic Devices

Saleem Khan, Crenna Maude, Guy Voirin, and Raphaël Pugin

Micro & Nano Systems, CSEM, SA, Neuchâtel, 2000, Switzerland

We report on the latest developments of rapidly growing field of printed electronics with particular emphasis on the functional materials, fabrication process and characterization of microelectronics and sensors on nonconventional substrates. Among the list of existing printing processes, we focus on the most promising i.e., aerosol jet printing (AJP) technology for its high-resolution patterning capability of metal lines as well as wide area coating of insulation materials. The additive manufacturing through AJP has revolutionized the field of printed electronics and has strengthened the promise for dense integration of electronic components on variety of substrates. Prospects of processing a wide range of materials including conductors, semiconductors, insulators, and epoxies make AJP a versatile tool for multilayered printed and flexible electronic devices. Processing of nanoparticles-based colloids as well as polymeric nanocomposites with a wide range of viscosities (1-1000 cP) and less processing parameters make AJP distinguished from other printing technologies. The capability of AJP to print ~10μm wide patterns makes it appealing for high resolution printing compared to conventional inkjet or screen-printing technologies which have print resolutions of > 60 μm at ideal conditions. Similarly, the wide nozzle feature of AJP allows for coating wider areas at rapid speeds producing optimal results especially the thickness and uniformity of the thin films. Here we report on the printing of various functional materials including metallic, polymeric, insulator and epoxies for development of different prototypes related to functional 3D parts, precision engineering as well as sensing applications. Nanoparticles based inks i.e., gold (Au), silver (Ag), AgCl, and platinum (Pt) etc. are used to print conducting tracks at 20 μm width on planar as well as non-planar surfaces. Besides printing on 3D printed parts, interconnects and insulation/encapsulation layers on the packaged chips are also presented. Different polymeric materials such as PEDOT-PSS and its nanocomposites with graphene, CNTs etc. are printed to manufacture different sensing structures. Process parameters are optimized considering printing results on substrate such as pattern resolution, uniformity, overspray at the edges, aspect ratio and finally on the electrical performance of the printed structures.

Laser induced forward and reverse transfer for additive manufacturing of multimaterial micro components

Minh Tri Nguyen[1], Tommaso Raveglia[1], Dario Crimella[1], Alberto Colombo[2], Matteo Bozzani[2],
Christian Piovera[2], Ali Gökhan Demir[1]

[1]Department of Mechanical Engineering, Politecnico di Milano,. Via La Masa 1, 20158 Milan, Italy
[2]Technoprobe, Via Cavalieri di Vittorio Veneto 2, 23870 Cernusco Lombardone, Italy

Pulsed laser can be used to eject materials from transparent donors through an ablation based expulsion mechanism. The material ejection can be controlled through the correct design of the donor materials and the laser optical setup. The ejected material in the form of sub-micrometric droplets can be stacked in order to achieve freestanding 3D components in the micrometric scale. This work depicts the use of a femtosecond pulsed UV laser to deposit material from solid donors in forward and reverse transfer modes in a flexible manner. The system architecture and the process development were carried out as a collaboration between Technoprobe and Politecnico di Milano. In the laser induced forward transfer (LIFT) mode, PVD produced pure titanium layers deposited on transparent glass is deposited in a drop-by-drop fashion to produce free-standing 3D micro metal objects. In the laser induced reverse transfer (LIRT) mode solid metals are transferred to transparent media to produce 2D layers with in-situ material mixing capabilities.