The Growth of Inkjet in Non-Graphic Applications

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IMI

IMI Inkjet Conference, Orlando FL
18-19th May 2023

GIS GLOBAL INKJET SYSTEMS
A NANO-DIMENSION DIVISION

GIS – Products Overview

GIS technology provides complete CONTROL from DIGITAL pixel to PHYSICAL drop

Atlas®
Machine Control
Engineering Interface

Printhead
Drive Electronics

Ink/Fluid
Delivery Systems

We work with world leading companies from R&D, Prototype Development - through to Production

GIS | GLOBAL INKJET SYSTEMS
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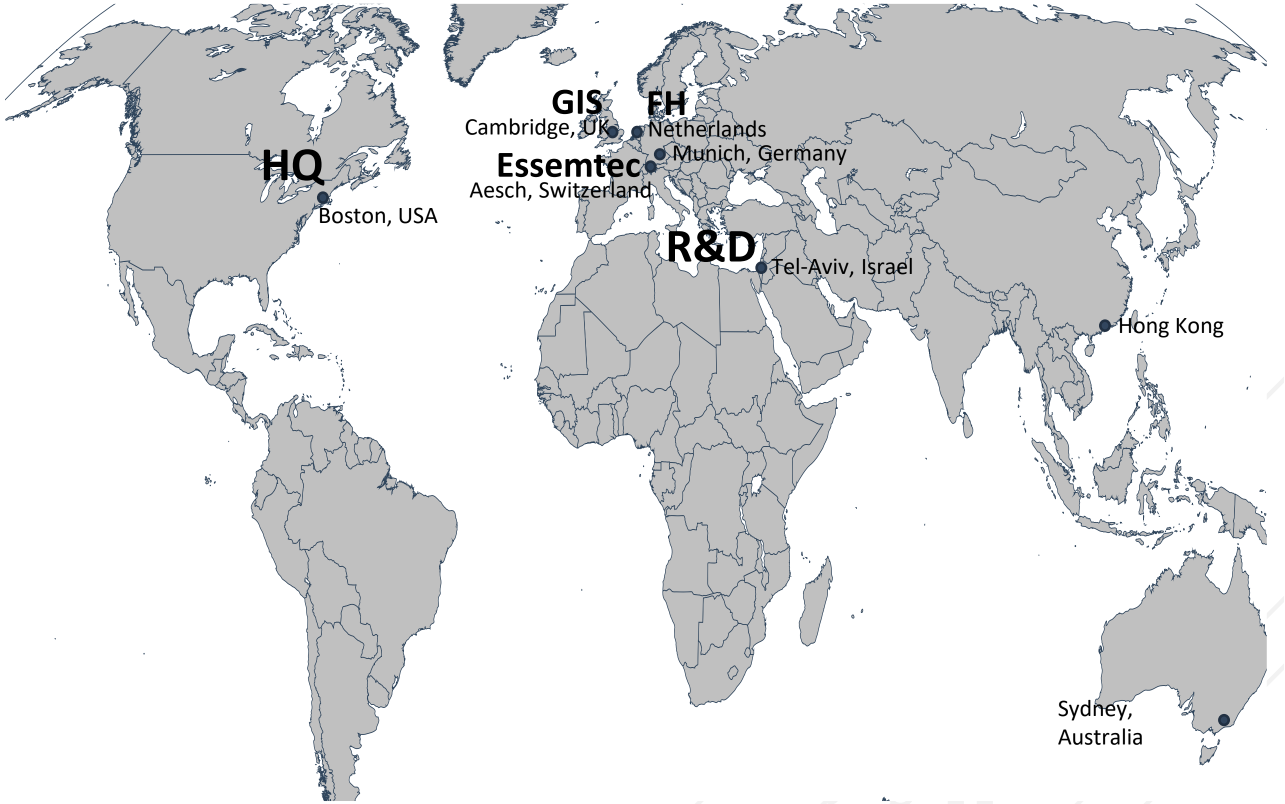
GIS - Overview

- **Datapath Electronics**
    - Support wide range of piezo inkjet printheads
    - Versatile – wide range of waveform ranges & slew rates
    - Advanced diagnostics
    - Production proven in manufacturing environments
- **Software**
    - Hardware agnostic & increasingly modular
    - We provide configurable workflow - and
    - Interfaces to 3rd party products
        - Vision systems, other diagnostic systems
    - Atlas IQ Tools for improving Image Quality
- **Ink / Fluid Delivery Systems**
    - Modular systems – from prototype to production
    - All flow modes supported
    - Large range of components specified for system requirements
        - Header tanks for challenging fluids
    - Long lifetime and long service intervals

Update on GIS

- **GIS** was acquired by **Nano Dimension** in Jan 2022
  - Customer of GIS for many years
  - GIS Founder, Nick Geddes, now Senior CTO at Nano Dimension
  - ~75 staff
- GIS core business continues as before

- **Nano Dimension**
  - Founded in 2014 – initially focused on printed electronics – now broader focus of digital manufacturing
  - NASDAQ listed (NNDM) – raised ~$1.5bn
  - Several acquisitions so far – and more expected
  - ~545 employees
    - ~46% in R&D & technical/application support
    - ~35 data scientists & algorithm engineers dedicated to AI (Artificial Intelligence) development



Nano Dimension

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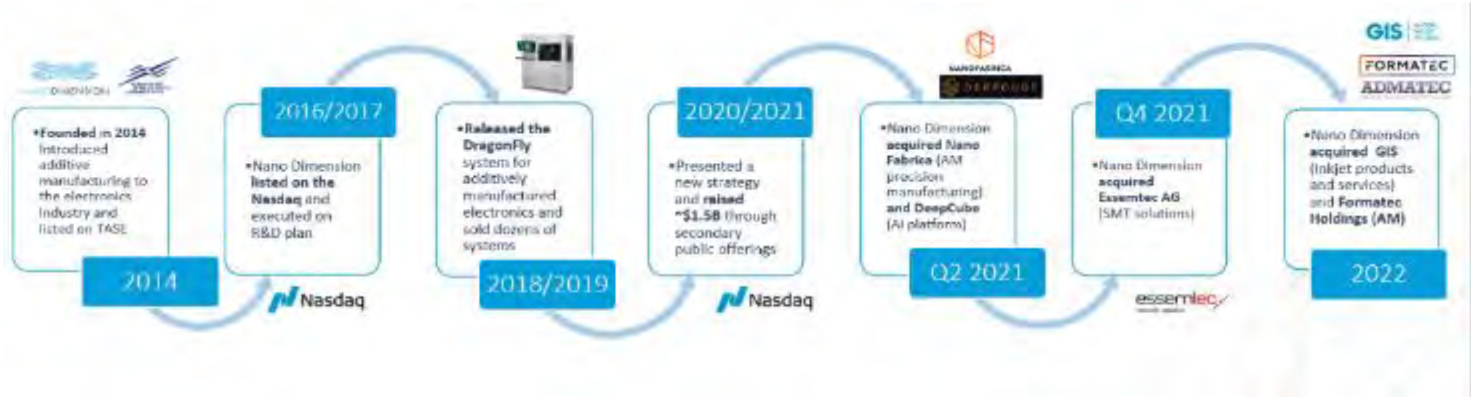
THE JOURNEY SO FAR

Nano Dimension is expanding its technology and product portfolio to achieve its vision:

Environmentally friendly & economically efficient production: **Smarter, Better, Faster**



NANODIMENSION DEEPCUBE GROUP

Driven by **DeepCube Group**: Deep Learning software embedded in printers and systems for realtime self-learning and correction

NANODIMENSION Electrifying Additive Manufacturing 	NANODIMENSION FABRICAGROUP ADMATEC 	essemtec A NANODIMENSION DIVISION 	GIS GLOBAL INKJET SYSTEMS A NANODIMENSION DIVISION 
AME (Additively Manufactured Electronics)	**AM (Additive Manufacturing)**	**SMT (Surface Mount Technology)**	**Digital Deposition Technologies**

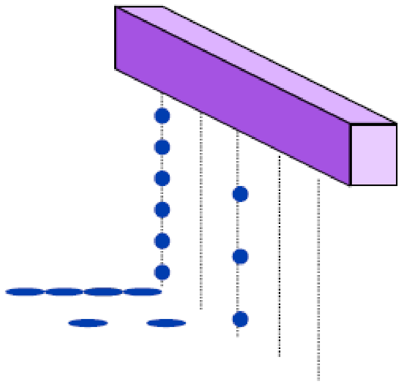
Disclaimer

GIS supplies inkjet technology and components to 150+ original equipment manufacturers world-wide. As a matter of policy, and subject to NDAs, we do not disclose our customer relationships.

Some of the following slides contain images chosen to illustrate the range of inkjet applications which are available in the market. The presence, or absence, of any manufacturer's products in these images does not in any way imply a commercial relationship between that manufacturer and GIS.

Inkjet in Non-Graphic Applications

- Inkjet is an additive manufacturing technology – increasingly used to jet functional materials in non-graphics or industrial manufacturing applications
- Functional materials may include fluids with conductive, optical, dielectric or chemical properties
- Advantages of inkjet are well known
    - Digital files - no plates, masks or screens
    - Non-contact / throw distance
        - No damage to fragile substrates / can fill cavities / deposit on top of existing 3D topology
    - Drop on demand – materials usage reduced
        - Strong economic and environmental advantage
- Challenges
    - Fluid compatibility limitations
    - Laydown limitations
    - Competing against very well established analogue technologies such as screen, spray, vacuum deposition etc.



Drop on demand

drops generated only when required

Inkjet in Non-Graphic Applications

- Printheads were originally designed for 2D text/graphics
- Increasingly now seen as precision deposition devices for manufacturing processes
  - New applications developing – creates new opportunities
- These new users are often not familiar with inkjet
  - Can be challenging for companies adopting inkjet for the first time to understand the capabilities and limitations of inkjet
  - Important to educate these new system builders/new users and manage expectations

- Fluid and process development are critical
  - Fluids and processes enable new applications
  - Improve the existing applications
  - Continuous development required

- However attractive inkjet may be – it is critical to find where the technology adds value

Viscosity Capabilities Increasing

Xaar, UK

Ultra High Viscosity Technology

Jet fluids around 100 centipoises (cP) at jetting temperature

Xaar's Ultra High Viscosity Technology allows us to jet fluids around 100 centipoises (cP) at jetting temperature, equating to approximately 1000cP at ambient temperature – going well beyond average jetting capabilities of 10-12cP, creating a number of benefits to ensure Xaar's printheads delivers high impact, productive and efficient results.

https://www.xaar.com/en/resource-centre/pushing-the-boundaries-of-inkjet-technology-with-high-viscosity-printing/

Info source: www.xaar.com

Viscosity Capabilities Increasing

Quantica, Germany

March 2023

Quantica closes €14m Series A funding round ahead of NovoJet 3D printer shipments

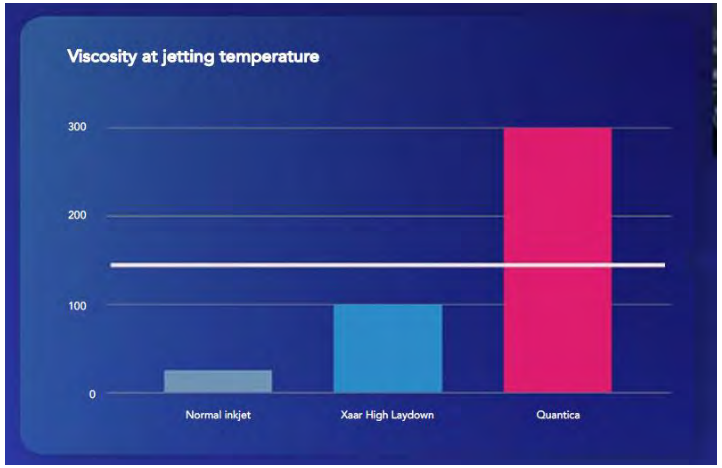
BY SAM DAVIES 12 APRIL 2023 13:00

Multi-material 3D printing firm Quantica has announced the closure of a 14 million EUR Series A financing round.

A full 10 million EUR has been secured by the Berlin-based company, with a further 4 million EUR attainable on the basis that certain milestones are met. The investment round was said to be led by a family office with ties to the dental industry, with participation coming from venture capital firms byFounders and Scale Capital, as well as senior employees and management.

Quantica's NovoJet C-7 multi-material 3D printing

https://uploads-ssl.webflow.com/635a85d9c66f9dc6314612b0/636bd816728b688c4f8d8b16_Quantica_NovoJet_Whitepaper.pdf



Nozzle count	96
Rows of nozzles	1
Nozzle pitch	<1.27mm
Dimensions (LxDxH)	130mm x 18mm x 25mm
Nozzle exit diameter	60um
Drop volume	25pl – 600pl
Fluid viscosity range	1mPa s – 300mPa s
Operation temperature setting	15C – 110C
Jetting Frequency	>4.8 kHz (provisional)
Minimum Life	All spec met after $3\ 10^{10}$ d/n
Guaranty	1 year with certified fluids
Fluid flow type	Full back of nozzle recirculation
Fluid surface tension	20mN/m – 75mN/m
Nozzle plate	PI

The UHV Print Engine 1.5

- First commercial version
- Based on original technology, fully redesigned
- Initially specified for dental application
- Aimed at high viscosity, low productivity
- Full fluid recirculation
- Heated and temperature controlled
- Planned introduction in 2023 on proprietary desktop printer

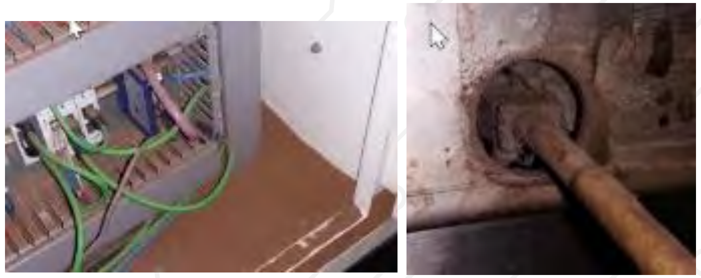
Info source: www.quantica3D.com

3D

3D

- Material jetting (ML)
- Binderjet – sand, metal, ceramics…
    - Sand binderjet - moulds for metal casting
        - Binding agent deposited onto a thin layer of foundry sand
        - Enables foundries to reduce long lead times
        - Design freedom – complete assemblies instead of several individual parts
        - Very large parts can be produced
    - Metal binderjet – jetting binder into metal powder – then sintered
        - Suitable for small to medium sized parts
            - Challenge to create binders for greater strength
            - Prolific development of new materials
        - Design freedom – array of geometries
        - Scale compensation required for shrink during sintering
        - Post processing required for optimum finish
        - More competitive than laser powder bed fusion

- Significant market for inkjet
    - Large XYZ systems / large numbers of printheads
    - Careful design required to avoid contamination within the system

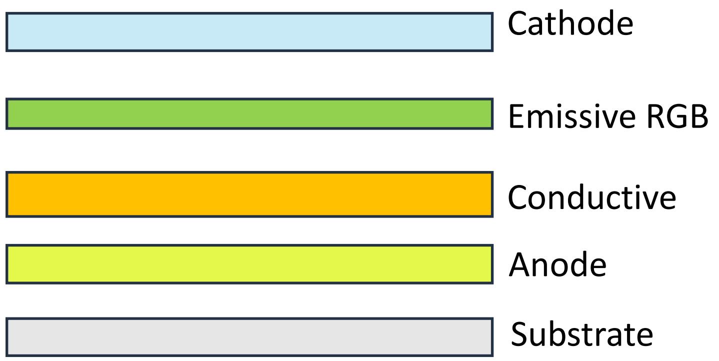


Display

OLED

- A flat light emitting technology, made by placing a series of organic thin films (usually carbon based) between two conductors. When an electrical current is applied, light is emitted.
- Traditional manufacturing uses evaporation processes in vacuum chambers
- Organic materials deposited onto the substrate (glass sheet) through a thin metal stencil (shadow mask)
    - Material waste
    - Mask vulnerable to contamination – lowers yields
- Manufacturers keen to explore alternative methods of production
- Inkjet can be deployed for soluble materials
    - Light emitting / Emissive layers RGB
    - Encapsulation

Simplified OLED Structure



OLED

- Inkjet enables precision deposition pf light emitting layers without using a mask
- Significant investment by OLED manufacturers in inkjet
- IJP OLED technology brings significant advantages: a wider colour gamut, lower power consumption, higher resolution, greater material utilization and lower production costs
- Manufacturers claim 20% lower cost than traditional methods
- Still in ramping up stage. Production currently believed to be relatively small but growing. China making huge investments
    - TCL CSOT – has previously showed 65” IJP-OLED display - jointly developed with JOLED, Japan
    - Next week at SID Display Week TCL CSOT will show a 65” inkjet printed foldable OLED display
- Controlling every aspect of printing is very challenging,
- Control of the quantity and size of each ink drop
- Position of the drop
- Status of ink (liquid viscosity to print)
- Drying process is also very important to make a uniform EL layer

OLED

- Thin Film Encapsulation (TFE) – for flexible displays
  - Typically polyimide flexible substate
  - Produce lighter, thinner and more durable panels vs. glass – also allows the development of fully flexible, foldable and rollable displays
- TFE is a multi-layer film made from alternating organic and inorganic layers
  - Inkjet commonly used to deposit the materials for TFE organic layers – replacing mask-dependent techniques like evaporation
    - Fewer defects, lower production costs, manufacturing scalability
    - Typical thin film printing $\leq 8\mu m$
    - Typical thickness uniformity $\leq \pm 4\%$
    - Random pattern printing capability
  - Several inkjet encapsulation system suppliers

Info sources: www.oled-info.com and web sites of Kateeva www.kateeva.com and Semes www.semes.com

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Recent News

December 2022: QD-OLED inkjet printers shipment

Kateeva starts to ship 8K QD deposition systems to Samsung Display

According to reports, Kateeva started to ship quantum dots inkjet printing equipment to Samsung Display, for the production of QD-OLED panels. It appears as if Samsung is interested in producing 8K QD-OLEDs, and its current inkjet printing supplier, Semes, is not ready with printers that support 8K QD deposition.

March 2023: JOLED files for bankruptcy

JOLED files for bankruptcy, Japan Display to take over assets

A report from Japan updates that JOLED , the OLED inkjet printing pioneer established in 2014, has filed for bankruptcy. The company has been struggling financially for a long time, and will now close down its two production lines and lay off 280 employees (out of 380), as it could not raise funds and has liabilities of around $257 million.

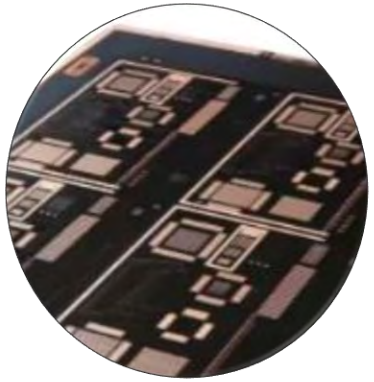
According to the report, display maker Japan Display will take over JOLED technology and remaining operations.

Info source: www.oled-info.com

AME
Additively Manufactured Electronics

Inkjet Printed Electronics

- Over 10 years of established technology and systems for printed electronics
- Typically single fluids – for a specific application
  - **Legend printing**
    - Reduces material use
    - Provides compact systems
  - **Solder mask**
    - Reduces process steps
    - Selective coating reduces material consumption
    - Non contact – no risk of damaging small solder dams between IC contacts
    - Allows different layer thickness
      - Typically 20-80μm – can be varied over the board to reduce material consumption
    - Accurate alignment and registration
      - Typically <2μm using automated fiducial alignment
      - Line space: typically < 75μm
      - Solder mask openings: down to 100μm
  - Several system suppliers now well-established in these applications



Additively Manufactured Electronics (AME)

- Multiple fluids (combining dielectric with silver nano inks)
- First stage of AME was to imitate traditional pcb 2D structures
  - But AME allows us to think differently
- In traditional pcb processes, the more layers required, the more complex and expensive the board
  - With AME - there is no additional cost to add layers. Also there is no limitation on the number of layers
- Plated Through Holes (PTH) is a lengthy and high-cost process that requires drilling, plating, etching and waste treatment. It is sensitive to registration between layers as number of layers increases.
  - With AME - registration issues greatly reduced. Entire process done by one tool with one printing process.
- Microvia manufacturing – expensive process. Laser drilling with via plating
  - With AME – no cost of building conductive filled vias. The AME process builds pillars between layers that represent the via connection.
  - Achieved during same printing process, no change of tooling, no drilling

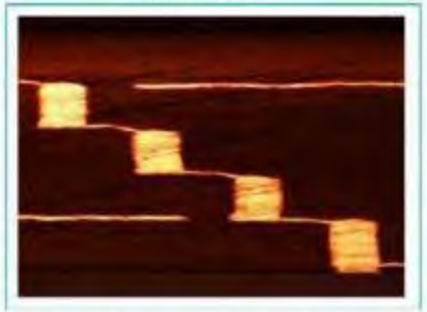
Multilayers

- No limitation on number of layers
- Near perfect registration between layers (same printing process)

PTH (Plated through-holes

We can do PTH, but vias don't add cost and actually improve performance

Microvias



We don't drill, we build pillars connecting vias between layers

Example results from Nano Dimension Dragonfly IV

Info and image source: Nano-Dimension

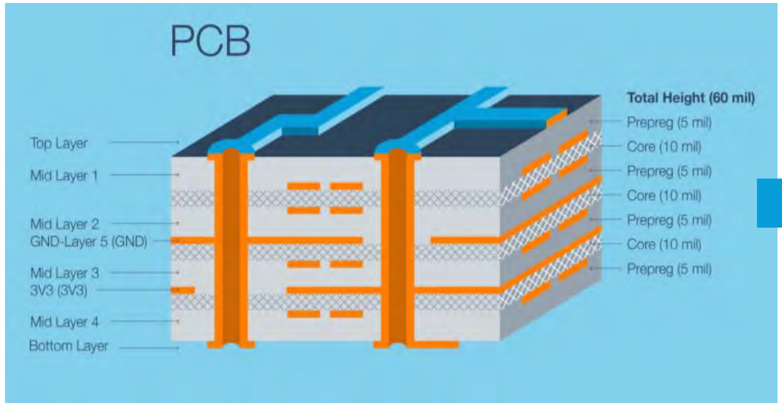
Additively Manufactured Electronics (AME)

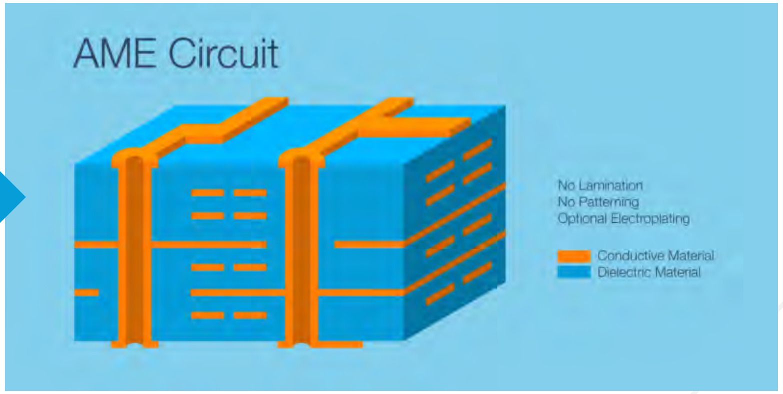
Process advantages

- Free form 3D electro-mechanical designs
- Device miniaturization
- Any layer routing
- Any angle routing
- Vialess routing
- "Real" twisted pair routing
- Compresses manufacturing processes

User advantages

- Produce cutting edge electronics in the lab
- Reduce weight and to miniaturize electro-mechanical components
- Retain IP
- Reduce time to market
- Optimize designs
- Create optimized electromechanical parts

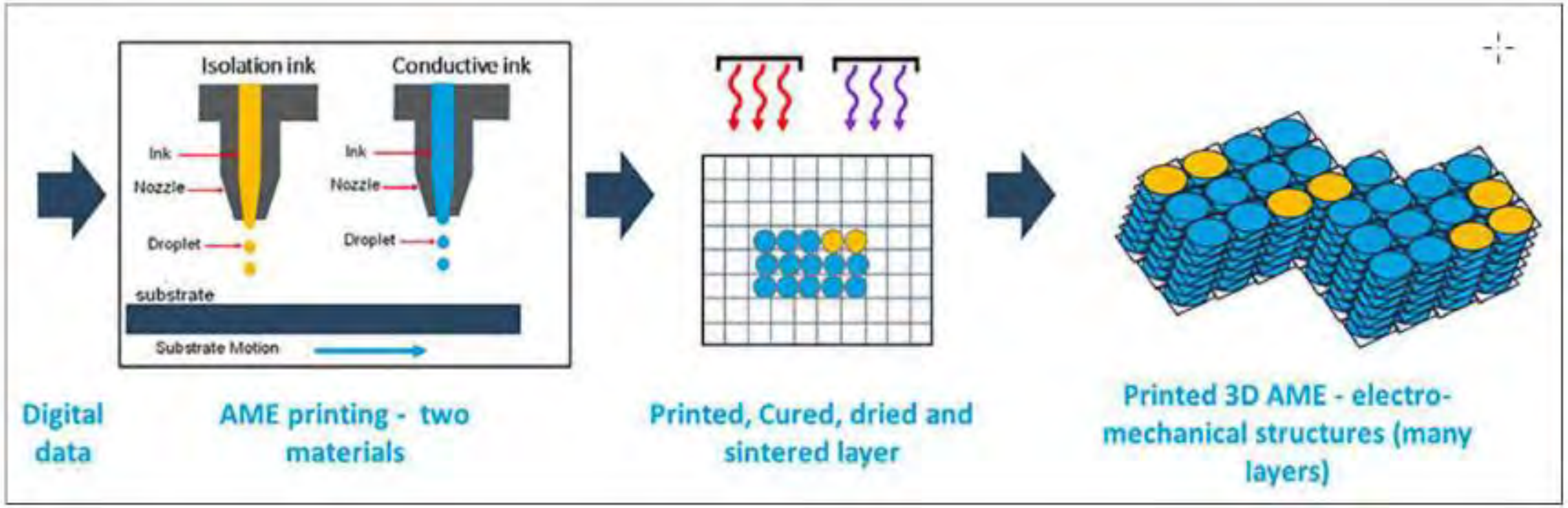




Info and image source: Nano-Dimension

Additively Manufactured Electronics (AME)

- Nano Dimension DragonFly IV uses inkjet technology (2 x printheads) to combine UV cured dielectric material (acrylic monomers) with silver nanoparticles, sintered under IR radiation
- Results in a solid object with conductive patterns and structures, created in shapes that are not achievable using traditional "2D" pcb manufacturing processes



- AME printing process – the ability to build complex 3D parts combined as conductive electronics and isolation structures, all performed in one print session

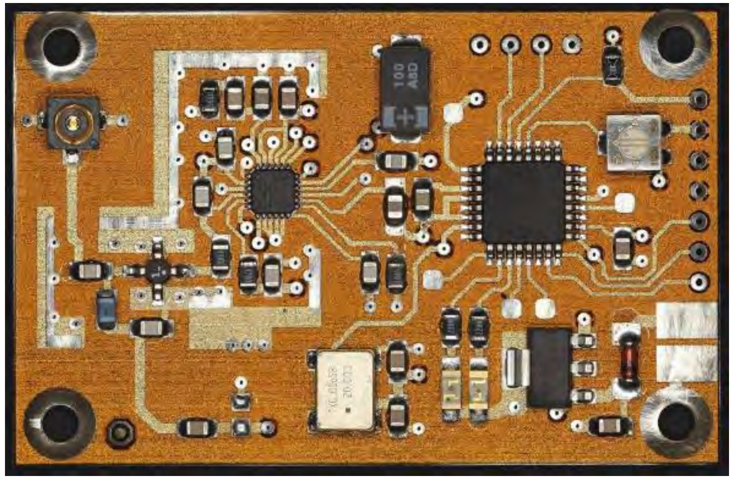
Nano Dimension DragonFly IV

Info and image source: Nano-Dimension

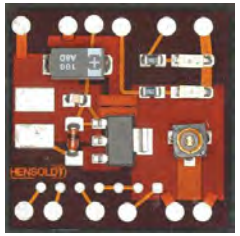
Example Use Case – Hensoldt Phase-locked Loop (PLL) Device

Hensoldt redesigned a PLL board for AME, achieving a new condensed and secure solution, unavailable in traditional technology

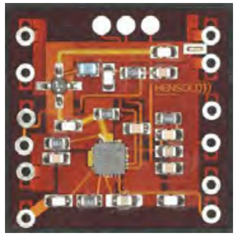
Original PLL board



3D printed interconnects
Embedded components

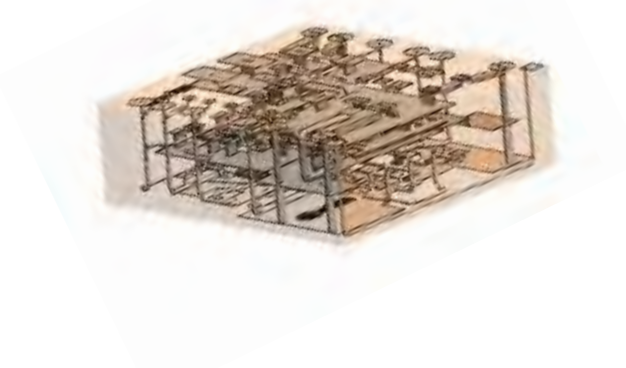


Layer #1

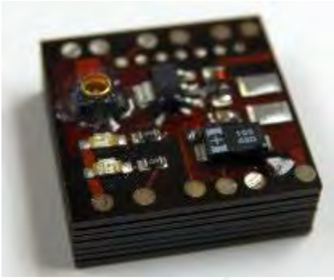


Layer #2

Layer #3

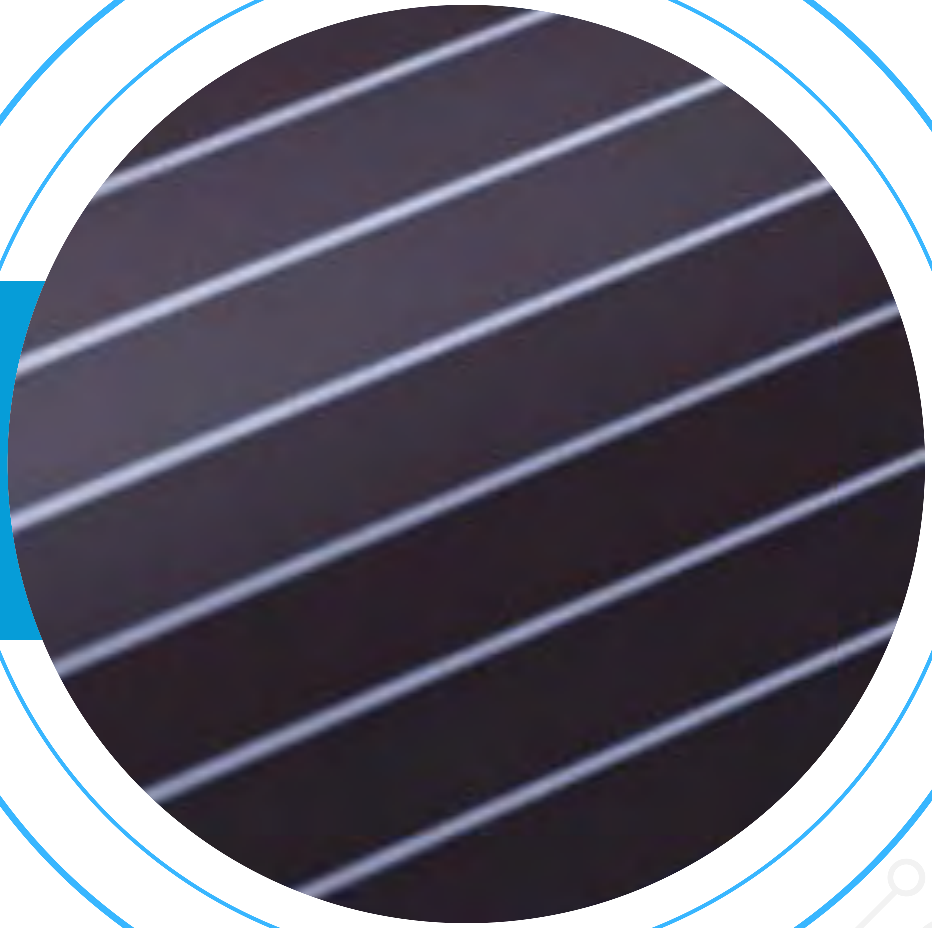


Stacked solution



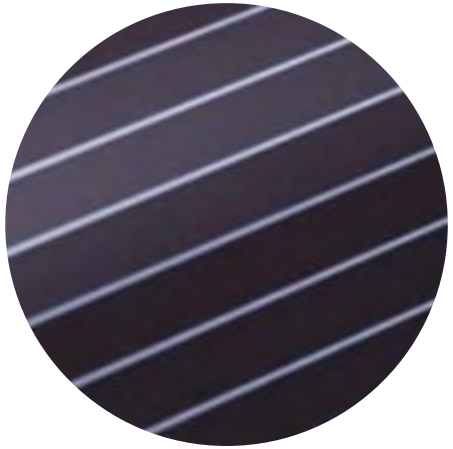
Info and image source: Nano-Dimension

Solar



Printed Organic Solar Cells (pOSC)

- Inkjet printing has already demonstrated its potential for fully-printed organic solar cells and organic photo detectors



Perovskite Solar Cells (PSC)

- Relatively new class of photovoltaic device
- Type of solar cell that includes a perovskite-structured compound for light absorbing layer
    - Typically, a lead or tin halide-based material
    - Unlike other high efficiency photovoltaic materials such as silicon, perovskite films can be easily crystallized from solution at low temperature. Enables devices to be fabricated quickly and at low cost
- Believed to be superior to other energy harvesting technologies
    - Flexible, low weight with high efficiency in artificial light
- Spin coating PSC being challenged by inkjet, blade or slot die coating and spray

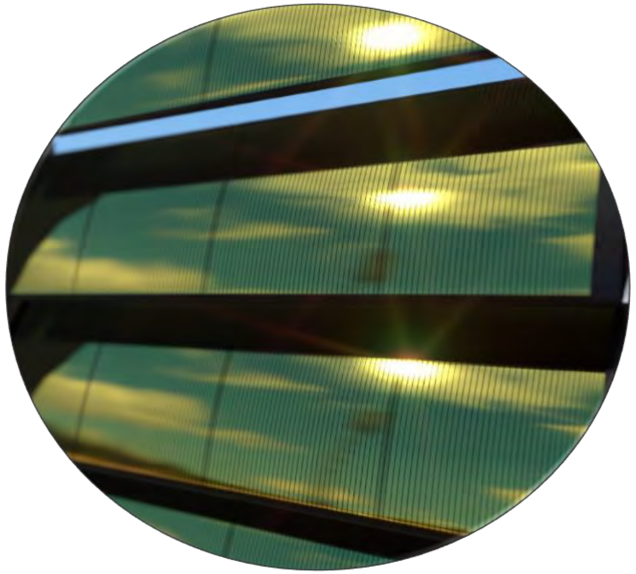
Printed Organic Solar Cells (pOSC)

- Key player in inkjet perovskite is **Saule Technologies** (Poland)
    - Claim to have launched the world's first industrial production line of solar panels based on perovskite technology using inkjet printing
    - 25.5% efficiency
- Commercial inkjet PSC applications
    - Electronic shelf labels
        - No battery. Powered by a perovskite photovoltaic cell
        - Cheaper and more convenient than traditional electronic shelf labels
        - Thin, lightweight and flexible
        - Contains wireless communication module
        - E-ink bi or tri-colour display
        - Enables fast pricing changes

Info sources: Saule web site https://sauletech.com/ and www.perovskite-info.com

Printed Organic Solar Cells (pOSC)

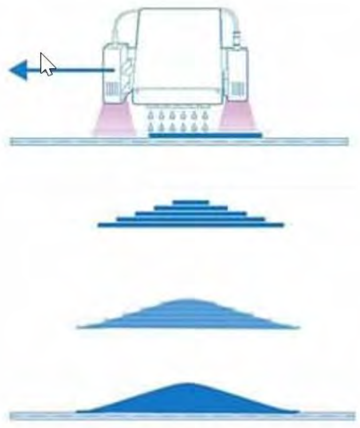
- Commercial inkjet PSC applications
  - Building Applied Photovoltaics (BAPV)
    - Lightweight rooftop solutions, energy harvesting sun blinds and awnings
    - Commercial product: an energy-harvesting kinetic façade that will block direct sun when needed ad reduce air con costs
  - Building Integrated Photovoltaics (BIPV)
    - Energy harvesting from walls and windows



Other Examples

(Some) Other Inkjet Applications

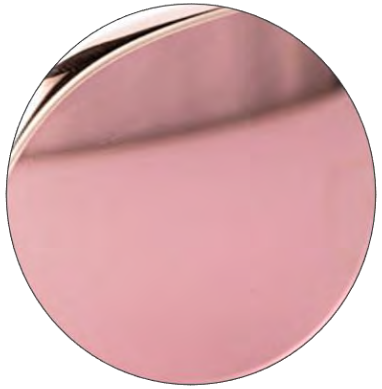
- **Lenses**
  - Jetting sunglass tints and gradients
  - Prescription lenses printed with 3D technology – building each layer – UV curing into lens shape – replacing the traditional multiple grinding and polishing steps
    - Luxexcel claims that their inkjet 3D process removes around 30 steps from their manufacturing process. 3D printed over 50,000 prescription lenses using its proprietary VisionPlatform technology.



Credit: Luxexcel

- **Waveguides**
  - Printing high refractive-index optical waveguides for Augmented Reality (AR) and Mixed Reality (MR) headsets
  - Traditionally created through laser ablation or photolithography
  - Inkjet used to print high profile linear patterns

(Some) Other Inkjet Applications



- **Functional coatings**
  - Anti-mist/anti-scratch/antimicrobial etc
- **Bio-printing**
  - Biological molecules (proteins etc) and cells (human or microbial)
- **Lithium ion batteries**
  - Jetting anode, separator and cathode fluids
  - Suitable for biosensors, wearable electronics and other miniature devices
- And many more…

(Some) Other Inkjet Applications

- **Temporary tattoos**
  - Prinker, South Korea (est 2015)
  - Handheld device ~ $279
  - Uses a primer and cosmetic-approved inks
  - Received investment from L'Oreal Jan 2023

- **Brow Make-up**
  - Brow Magic - joint development L'Oreal and Prinker
  - Uses AR technology & patented AI algorithms.
  - Device scans the user's face and makes recommendations on the best brow shape

Recent News

- April 2023: P&G phases out Opte – handheld make up application
    - Premium price $599 for FMCG company

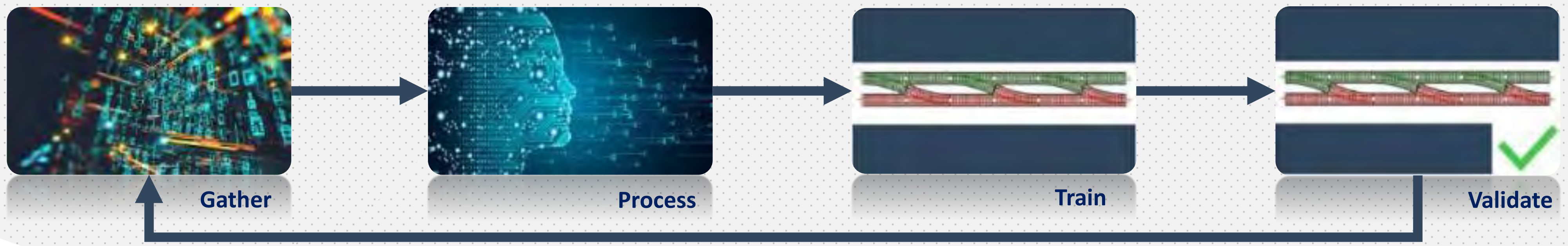
P&G Unwinds 'Precision' Makeup Brand Opte Four Years After Launch

After launching in 2019, Procter & Gamble Co. phases out beauty tech device

Machine Learning / Deep Learning

Machine Learning / Deep Learning

- Machine learning being implemented in printing/deposition systems – several announcements by major vendors in last two years
- In non-graphics, Machine Learning (ML) and Deep Learning (DL) will be used to examine sensor data for:
  - Machine performance (accuracy of physical components)
  - Material deposition/ jetting accuracy
  - Manufacturing environment data (temperature, humidity, vibration, etc.)
- Using deep-learning-based AI, systems and equipment will become automated, autonomous, self-learning solutions that enable higher throughput and greater yield



Machine Learning / Deep Learning from DeepCube

- DeepCube – acquired by Nano Dimension in 2021
- Real-time error detection and correction
  - o DeepCube applies the same neural network training behind photo and speech recognition advancements to the manufacturing of parts
- Improved part quality
  - o Multiple sensors can spot defects too small for the human eye to see
- Increased part yield
  - o AI-driven decision making corrects printing errors in real time
- Data speeds
  - o DeepCube's propriety algorithms increase the speeds of data analysis tenfold, making it the only hardware performance accelerator of its kind
- Distributed Global Automation
  - o AI turns machines into nodes
    - Coordinate multiple machines across a lab or across the world
    - Machines share learning inferences with each other for immediate adjustments in production flow

Summary

- In non-graphics, inkjet has good growth opportunities in many different applications and markets. We looked at several successful applications.
  - Inkjet is typically one part of the whole manufacturing process
    - Always key to find where inkjet adds value
    - Hybrid processes
  - Full process understanding is essential across all deposition methods
  - Materials and process for inkjet are critical – more development / more products required
- Machine Learning / Deep Learning will help optimise print and deposition processes
  - In future, expect to see more use of these technologies – leading to greater system stability and output
  - Predictive maintenance for the whole machine
- Added benefit of building a sustainable ecosystem
  - Efficient use of power and materials, with minimal waste to create an optimal product

NANODIMENSION
Electrifying Additive Manufacturing

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www.globalinkjetsystems.com