Master's Thesis Engineering Technology

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Room-temperature liquid metal direct writing: Developing and evaluating a modular deposition system

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Situation

This research is conducted at **IMO-IMOMEC**, a joint institute of the **University of Hasselt** and **IMEC**, specialising in multidisciplinary material research. The **Functional Material Engineering (FME) Group** focuses on **printing and coating functional devices, like flexible sensors.**

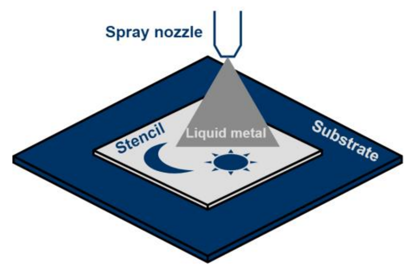


Figure 1: The spray coat technique

Problem Definition

Functional devices need precise application of **liquid metal conductors** on **silicone substrates**. The current **spray coat technique**, shown in Figure 1, uses a **stencil**, causing **significant material loss** and making **rapid prototyping difficult**. A **greener**, **more versatile** printing method is needed to apply liquid metal conductors precisely, with **minimal waste** and **greater flexibility** for the research group.

Objectives

The **primary objective** of this thesis is to develop a **modular 3D liquid metal printer** for stretchable electronics, **improving the inefficiencies** of **current spray coating methods**. The system will offer:

- Precise control of flow rate and pressure;
- Reliable height detection;
- Easy customization with swappable nozzles;
- Three-axis printing capability for 3D structures.

Literature Study

Applications

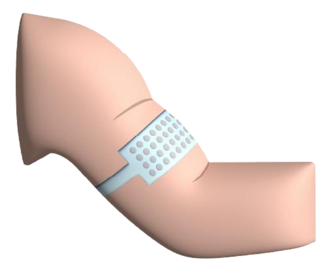


Figure 2: Wearable device

Functional devices, such as stretchable electronics, have **diverse** applications across industries:

- **Healthcare**: Wearable devices for continuous health diagnostics;
- **Consumer Electronics**: Comfort and adaptability in wearables;
- **Soft Robotics**: Allow robots to perform delicate tasks like humans.

Galinstan

Galinstan is an alloy composed of **68.5% gallium**, **21.5% indium**, and **10% tin** that remains **liquid at room temperature.** It has several **important properties**:

- High electrical conductivity;
- Low viscosity;
- Low toxicity.

Method

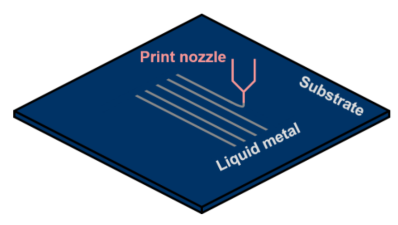
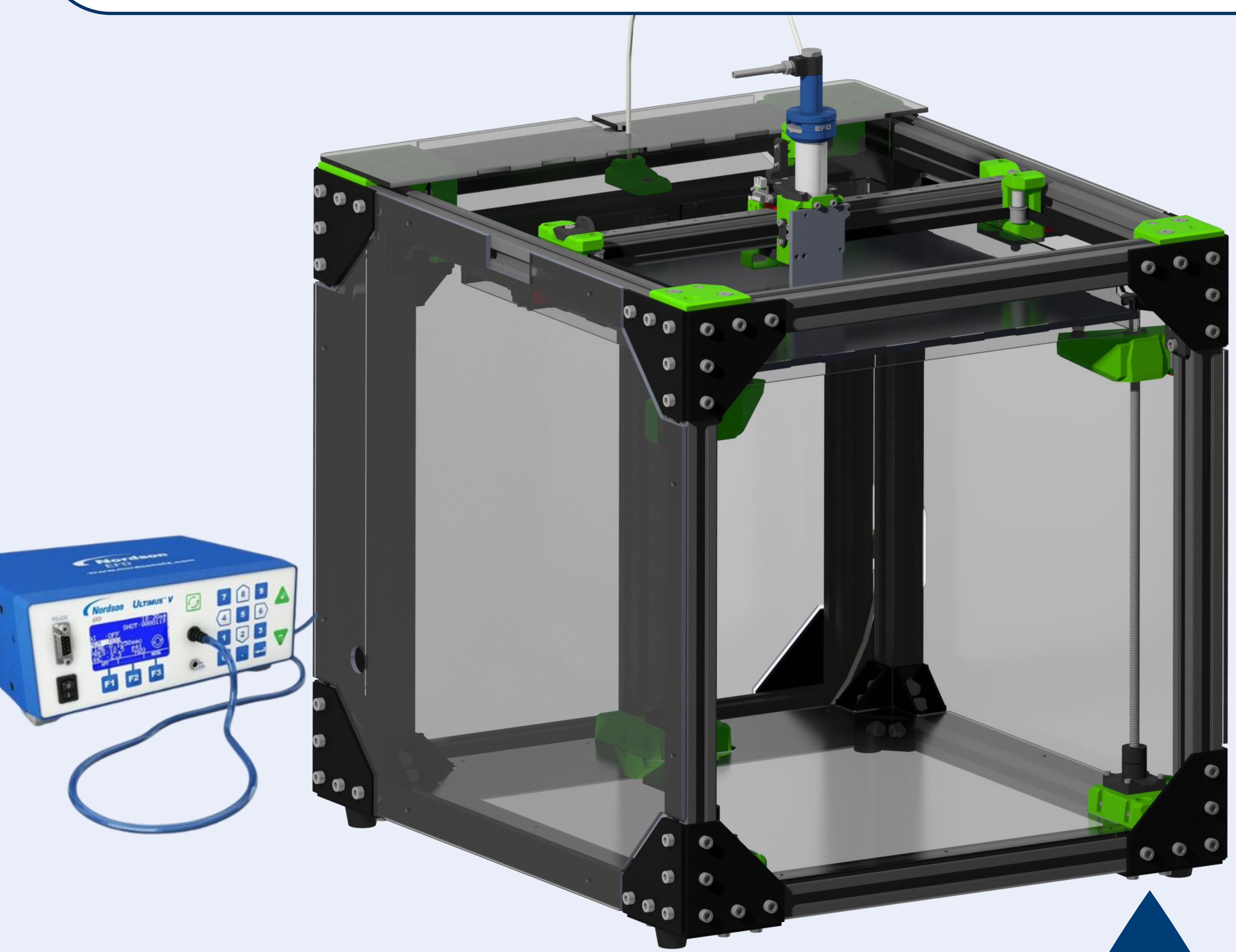


Figure 3: The direct write technique

The **direct writing technique** dispenses liquid metal onto the substrate with nozzles, **eliminating the need for stencils** and **enhancing material efficiency**, **precision**, and **flexibility**. Adjustable flow rates, pressures, and precise nozzle positioning ensure accurate application.



Design

The design process began with selecting a **modular RatRig 3D printer** for its flexibility. A customised system was developed, incorporating a **pump** and **interchangeable nozzles** for different line sizes. Additionally, a **height detection sensor** ensures **accurate print head distance** from the substrate, allowing for precise liquid metal deposition.

Figure 4: RatRig logo [1]

Dispenser

The **Nordson Ultimus V** dispenser ensures **precision** and **reliability.** It uses a **syringe-based system** with adjustable air pressure, preventing contamination and simplifying maintenance, making it **ideal for precise control** for **Galinstan**.

Figure 5: Nordson Ultimus V

Nozzle

The **Optimeter syringe** provides high precision dispensing and reliability. **Stainless steel needles** (200 and 510 µm inner diameter) were used to **study resolution**. The design ensures **consistent flow rates** and **minimises clogging** with an **etching process**. Swappable nozzles allow quick adjustments and maintenance.

Figure 6: Toolhead

Software

The printer uses **Klipper firmware** and **RatOS** for advanced control. **Klipper improves speed and precision** with a Raspberry Pi, while the motherboard handles **time-critical tasks**. Features include automatic **bed mesh levelling**, and **network management**. **Bed mesh levelling** adjusts for **substrate variations**, and RatOS provides an easy-to-use interface.

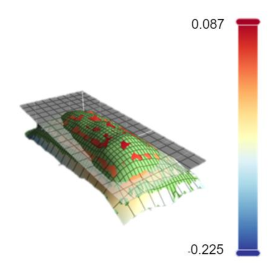


Figure 7: Bed mesh

Results

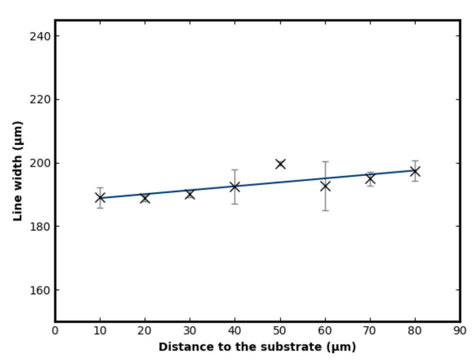


Figure 8: Distance to substrate vs. line width

Figure 8 shows a **positive linear relationship** between **substrate distance** and **line width** when printing with a **200 µm nozzle**. As distance increases from **10 µm** to **80 µm**, line width grows from **188.8 ± 1.0 µm** to **197,5 ± 3,2 µm**. This emphasises the importance of accurate distance control to print **consistent** and **precise lines**

Figure 9 compares line width and substrate distance for **510 µm** and **200 µm nozzles**. The **510 µm nozzle** has a **print range up to 150 µm**, while the **200 µm nozzle ranges up to 80 µm**. Consequently, the **510 µm nozzle** is **less susceptible to line breakage** due to **surface irregularities**, offers a **broader operational range**, and is thus **more reliable**.

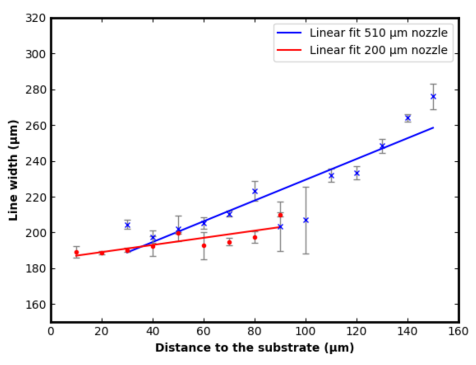


Figure 9: Comparison impact different nozzle inner diameters

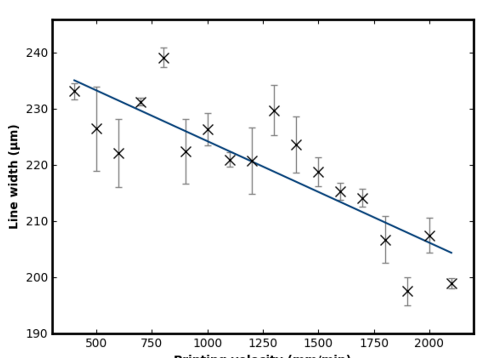


Figure 10: Printing velocity vs. line width

Figure 10, reveals a **negative correlation** between **printing velocity and line width** using a **510 µm nozzle**. As speed increases from **400 mm/min** to **2100 mm/min**, line width decreases from **233.1 ± 1.5 µm** to **216.0 ± 6.0 µm**, with **reduced variability at higher speeds**.

Devices

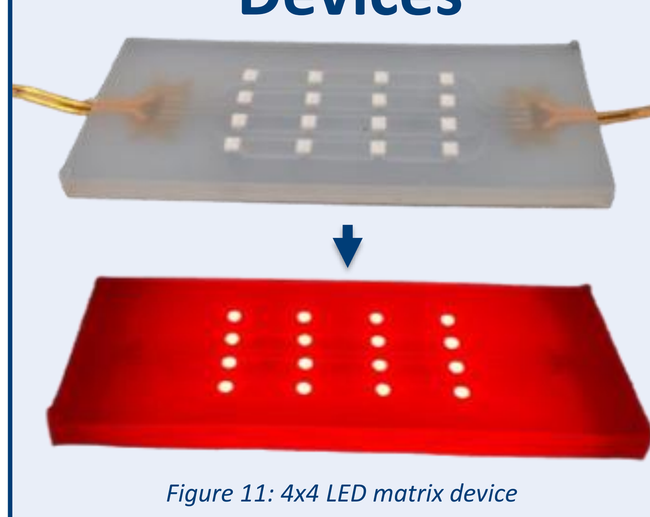


Figure 11: 4x4 LED matrix device

Figure 12: Double spiral device for pressure sensor

Conclusion

The master's thesis achieved all objectives by developing a system to **print liquid metal** on **flexible silicone substrates**. Both **extrusion-based** and **shear-driven direct writing** produced consistent lines. **Shear-driven writing** with a **510 µm nozzle** achieved a **line width of 186.7 ± 4.2 µm to 275.9 ± 7.2 µm**, confirmed by **successful device production**. Precise control of pressure and nozzle spacing was crucial. The modular design allows easy customization and future upgrades, advancing liquid metal printing research.

Figure 13: Stretched devices

Future Work

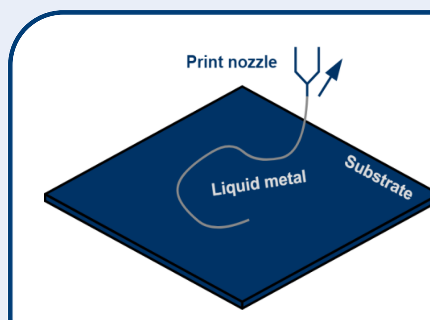


Figure 14: 3D print technique

Future work includes **further testing** and **optimization** with different nozzle diameters and materials, **fine-tuning printing parameters**, and **extensive characterization** for **3D printing** of liquid metal structures. Exploring new deposition techniques with this printer offers promising avenues for innovation.

[1] RatRig, "RatRig Logo," [Online]. Available: https://ratrig.com. [Accessed: 18-May-2024].

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