





Aerosol Jet Printing (AJP) technology for conductive trace printing

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Outline









- Introduction to Aerosol Jet Printing (AJP) technology
- Pneumatic atomization system in AJP
- Assessment of the printed conductive traces
- Results
- Future perspective

AJP technique capabilities



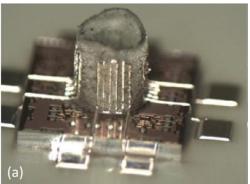


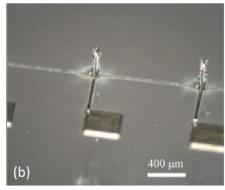




AJP is a non contact direct-writing and additive manufacturing machine







N. J. Wilkinson et al. A review of aerosol jet printing—a non-traditional hybrid process for micro-manufacturing, The International Journal of Advanced Manufacturing Technology (2019) 105:4599–4619

- 3 axis-coordinate motion
- Large range for stand-off distance
- Features with precison from mm to µm size scale
- Wide range materials compounds (dielectric, semiconductors, metallic, *etc.*)
- Contactless printing mode
- Planar and step surfaces substrates

Possible applications for detector development









Large-area sensors

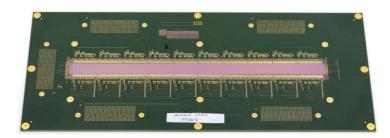
 Compensate for in-silicon power distribution inefficiency over long distances through post processing

Thin silicon

Contactless interconnections

Flexible material

Electrical circuit over non-planar geometries





Pneumatic atomization setup

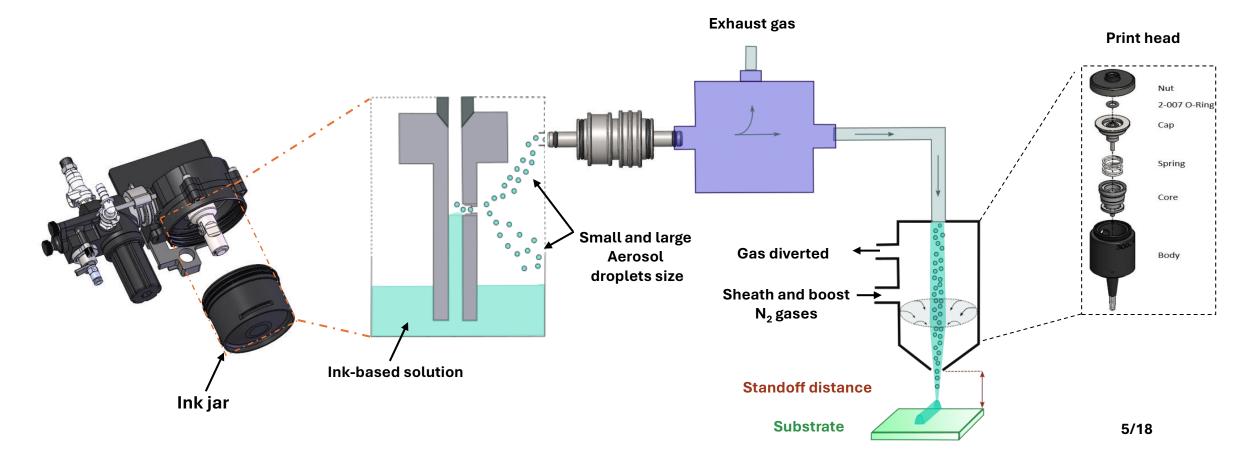








- The pneumatic atomizer uses a high-velocity gas stream to shear a liquid stream into small droplets of 1 to 5 μ m.
- A virtual impactor then removes excess atomization gas, thereby reducing the velocity and concentrating the aerosol stream prior to its delivery to the print head.



Schematic gas flow setting in AJP





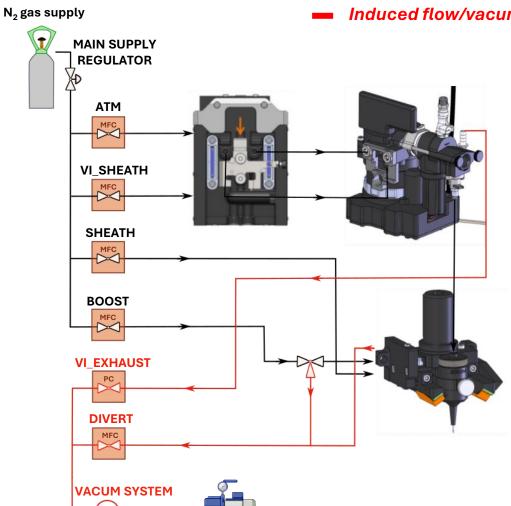






Forced flow/supply gas

Induced flow/vacum exhaust



- Several inlet gas flows (N_2) such as ATM, VI_SHEATH, SHEATH, and the BOOST are employed to aersolize the ink solution and focus during printing the aersol stream on the substrate surface.
- The outlet flows such as the VI_EXHAUST and DIVERT allow to ensure a proper stream pressure inside both the pneumatic sytem and the print head level, respectively.
- In particular, the sheath flow is employed to collimate the aerosol in a narrow stream during printing process, and it is commonly defined as the focusing ratio.

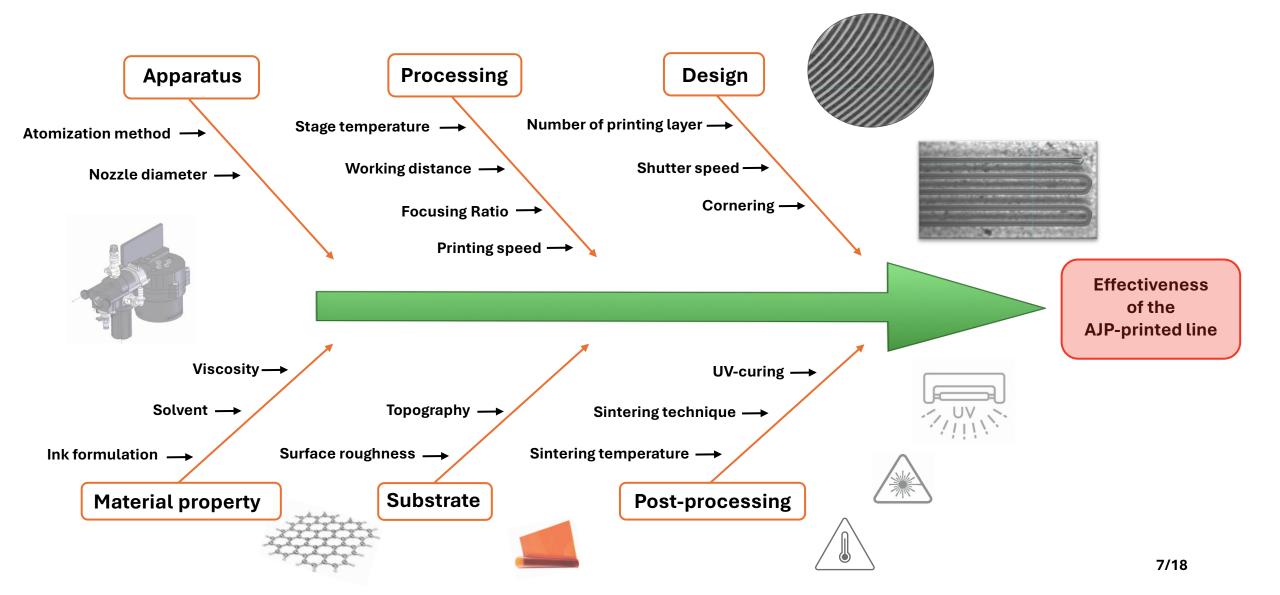
Parameters affecting the AJP-printed features











AJP Lab @ University of Trieste











A photograph taken for the AEROSOL JET HD2 instrument provided by OPTOMEC company.

- AJP funded by the University through a 'large instrumentation call'
- Interdisciplinary research (Physics, Engineering, Chemistry Departments)
- Received additional funds for material and personnel through 'EIC Generic R&D Program' for silicon embedding

Material preparation and sintering-processing



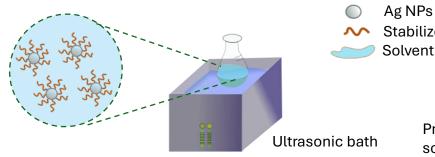






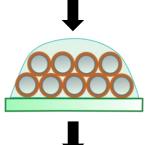
	Ultrasonic atomization	Pneumatic atomization
Suitable phase	Solvent, solution, dispersion	Solvent, solution, dispersion, liquid monomers
Viscosity range	(1-10) cP	(1-1000) cP
Maximum solid loading	55 wt. %	85 wt. %
Maximum particle size dispersion	50 nm	2 μm
Solvent	Low boiling point	High boiling point

A solution made of commercial silver (Ag) nanoparticles (NPs) based-ink (LOCTITE ECI 1011 E&C) and propylacetate solvent has been prepared at 50 wt.% and investigated by means of the pneumatic atomizer AJP setup.



Stabilizer Solvent

> Presence of residual solvent on the single printed trace

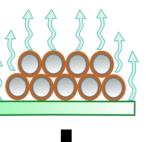


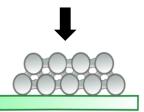
AJP Pneumatic printing

of single line

Thermal drying to evaporate solvent

Thermal syntering to remove stabilizers and promote the coalescence of Ag NPs





An example of printed Ag-based lines on microscope slide substrate after thermal sintering carried out at 200 °C (2h).

Increasing conductiviy

AJP printing procedure









Each printing session requires a sequence of steps:

- 1. Preparation and assembly of the printer components
- 2. Preparation of the ink in the proper solution
- 3. Formulation of printing recipes (gas pressures)
- 4. Definition of printing sequence
- 5. Printing pattern CAD design and conversion
- 6. Sintering of the printed samples

Pneumatic Assembly in AJP-LAB





















Ongoing investigation of printing parameters with silver ink

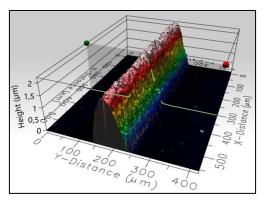




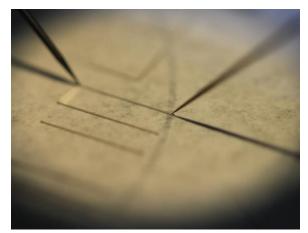








On the left, a set of AGP-based silver traces printed on microscope slide substrate, with an example (right) of a profilometer measurement obtained for a single line.



Electrical characterization of the Agbased printed line.

- A solution made of commercial **silver (Ag) nanoparticles (NPs) based-ink** (LOCTITE ECI 1011 E&C) and propylacetate solvent was prepared at 50 wt.% and aerosolized by using a pneumatic atomizer AJP setup.
- The Ag-based lines were printed on glass slide substrates, and further **sintered at** ~200 °C for 2 hours in a conventional oven.
- Several number of printing conductive Ag-based layers were performed on the same trace, by setting different values of the following processing parameters:

 Sheath gas flow, and nozzle printing speed.
- The effect of these parameters on the geometry and conductive properties of the Ag-based printed traces was investigated by measuring the profiles and resistance with a profilometer and probe station instruments, respectively.
- The resistivity value was obtained and compared with those reported in literature.

Process parameters on the geometry of Ag-printed lines





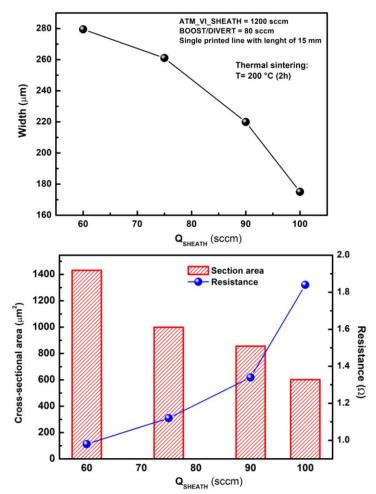




• Influence of both Sheath gas flow and printing speed on the conductive performance of single silver printed line:

An example of Ag-based lines printed on glass slide substrate.

Varying the Sheath flow at the head nozzle



Process parameters on the geometry of Ag-printed lines

280

260









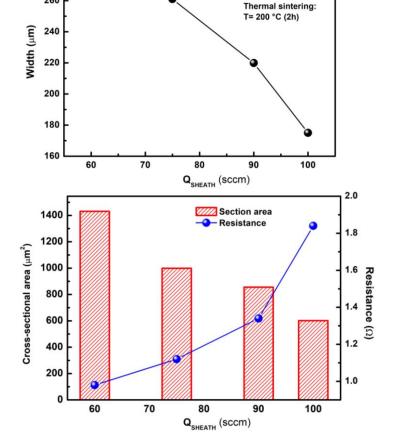
• Influence of both Sheath gas flow and printing speed on the conductive performance of single silver printed line:

ATM VI SHEATH = 1200 sccm

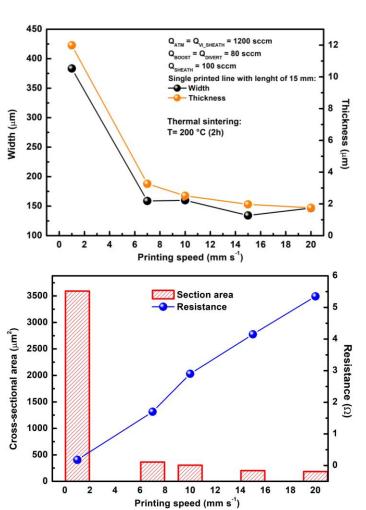
Single printed line with lenght of 15 mm

An example of Ag-based lines printed on glass slide substrate.

Varying the Sheath flow at the head nozzle



Varying the Printing speed



Repeated single-line printing

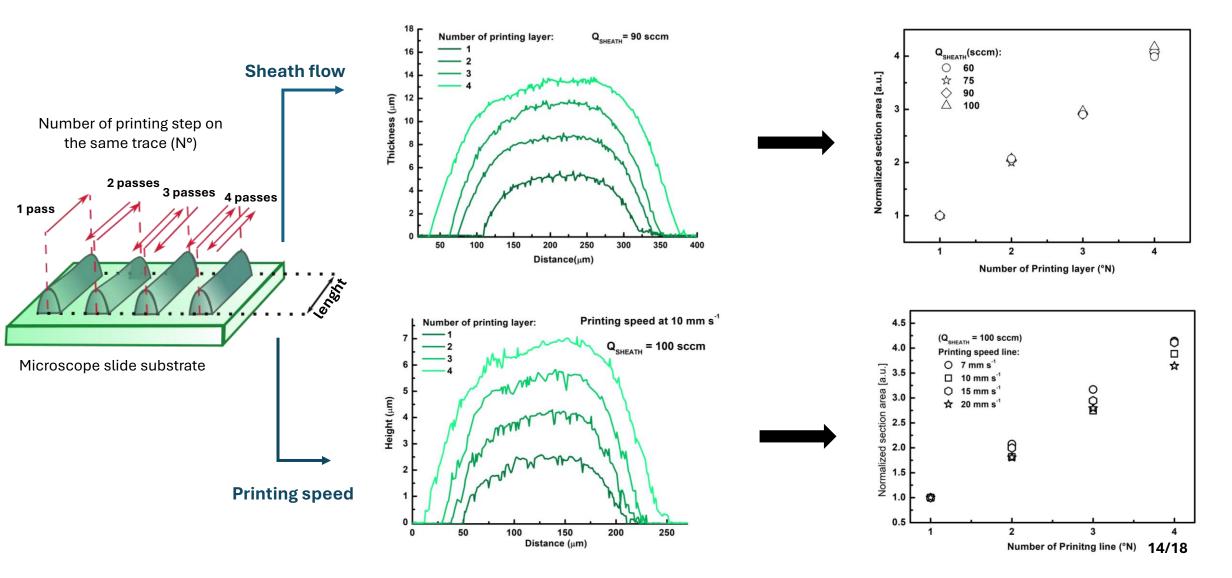








• Influence of Sheath gas flow and printing speed on the repeated conductive Ag-printed line:



Repeated single-line printing

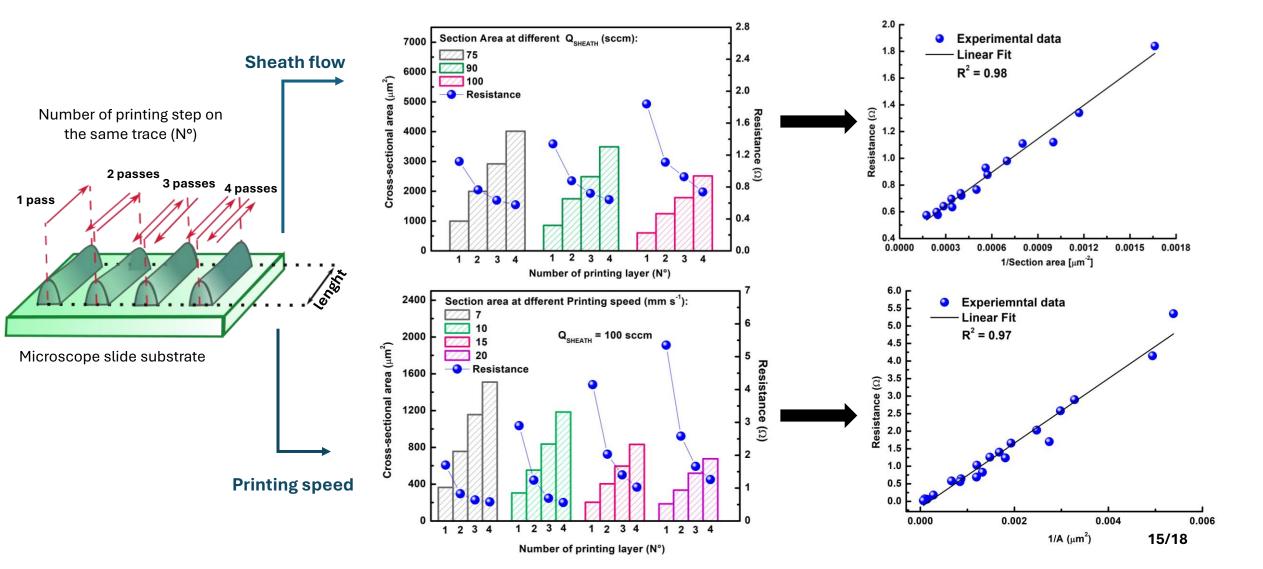








• Influence of Sheath gas flow and printing speed on the repeated conductive Ag-printed line:



Resistivity studies versus literature









TableList of the resistivity measured for different AJP silver-based printed lines for a comparison.

Substrate	Thermal sintering (°C)	Resistivity (10 ⁻⁸ Ω∙m)	Ref.
Glass slide	100	8.76	1
Glass slide	150-300	5.6	2
Paper and polyethylene terephthalate (PET)	50-180	10-100	3
Glass slide and polymide	200	6.6	4
Glass slide	200	5.6 ± 0.2	This work
Glass slide	200	6.1 ± 0.2	This work
Bulk silver		1.466	5

• The resistivity values obtained from the electrical analysis carried out on the conductive Ag-based lines were comparable to those reported in literature, in the range of the sintering's temperature considered here.

References

[1] Atef Abu-Ageel *et al.*, Low-temperature pulsed-light assembly of nanoparticle silver ink. ACADEMIA MATERIALS SCIENCE 2023, 1.

[2] Iara J. Fernandes *et al.*, Silver nanoparticle conductive inks: synthesis, characterization, and fabrication of inkjet-printed flexible Electrodes. Scientific Reports, (2020) 10:8878.

[3] Wenfeng Shen *et al.*, Preparation of solid silver nanoparticles for inkjet printed flexible electronics with high conductivity; Nanoscale, 2014, 6, 1622.

[4] Yongkun Sui et al., An Aerosol Jet Printed Resistance Temperature Detector-Micro Hotplate with Temperature Coefficient of Resistance Stabilized by Electrical Sintering. Adv. Mater. Technol. 2023, 8, 2202053.

[5] C. Crump *et al.*, UV Flash Sintering of Aerosol Jet Printed Silver Conductors for Microwave Circuit Applications; IEEE transaction on component, packing and manufacturing technology, vol. 11, no. 2, february 2021.

Conclusion and future perspective









- We systematically investigated the influence of the AJP process variables on the printing of Ag conductive traces.
- We acquired a good control of the printing process that translates into the ability to print a pre-defined geometry.
- Measured resistivity values are in line with the published ones.
- Next steps:

Different substrates (flexible, plastic, etc.)

Different sintering temperature range

Non-conductive inks solutions

Electrical interconnections

Recent AJP implementation in interdisciplinary research applications



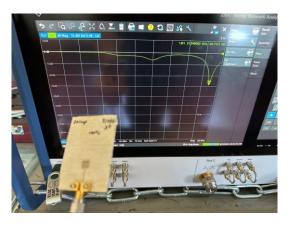


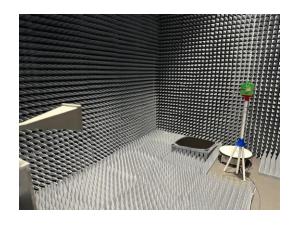




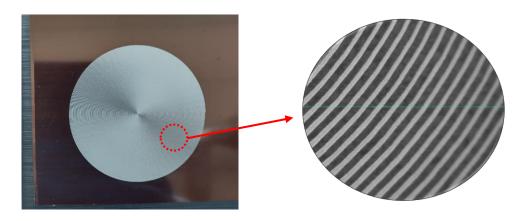
- **microstrip antenna prototypes**: Radiation pattern and reflection coefficient were experimentally measured under far-field conditions in the anechoic chamber at the University of Trieste.
- The results of this study will be presented to the next EUCAP 2026 conference.

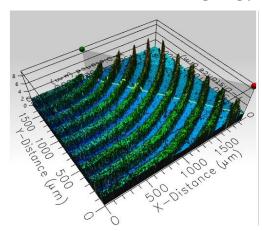






- Realization of new printed geometries as absorber devices for X-Ray imaging (Characterization studies ongoing):













Thank you for your attention