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Characterization and Optimization of Dispensing Process of Die Fillets

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Introduction

Filleting in flexible hybrid electronics

- Components of various thickness may be placed on a substrate and, in order to be integrated with each other, robust interconnects are to be printed between different leveled surfaces [1,2].
- Fillets are fabricated around rigid components to create smooth transitions between the surfaces.
- Filleting allows integration of SMT rigid components with printed electronics [3].
- Gu et al. [1] proposed a method to effectively fillet components using aerosol jet printing technology.

Dispensing

Dispensing is a printing technique that allows to deposit materials based on a programmed toolpath. It offers several advantages both over conventional and 3D printing processes, making it suitable to several applications.

Why using dispensing to fillet dies

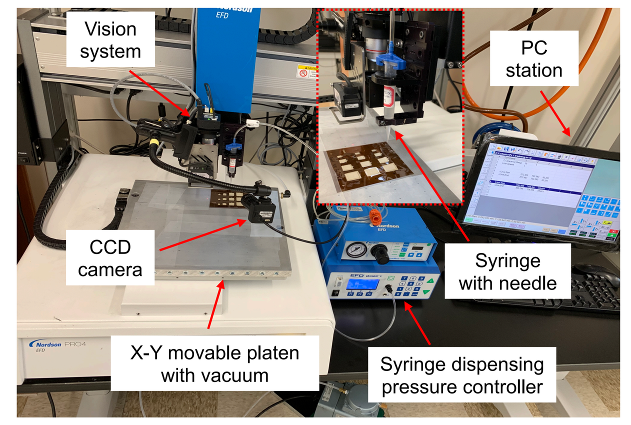
- Dispensing is compatible with a wide range of functionalized inks [4], including screen printable inks.
- Dispensing provides a process that is faster than AJP, allowing to deposit large amounts of material still achieving the precision required by this application.
- Dispensing systems are much easier and cheaper to operate and maintain than AJP systems.

Objectives

- Develop a process to effectively fabricate die fillets through dispensing, in order to create smooth transitions between different leveled surfaces on a flexible substrate.
  - Dispensing can print large quantities of material at a much faster speed than AJP, still obtaining precise and repeatable results.
- Utilize resistance measurements of conductive lines aerosol jet printed over filleted dies to assess quality of die fillets, in order to characterize and optimize die filleting process.
  - Which factors significantly influence quality of die fillets?
  - What is the treatment combination that minimizes resistance?
  - Are the statistical conclusions confirmed by optical analysis?

Experimental Setup

- Nordson 3-axis PRO4L robot dispenser with CCD camera.
- Nordson Ultimus V syringe dispensing controller (with pressure and vacuum control).
- Binder convection oven to cure samples.
- Keyence 3D Laser Scanning Confocal Microscope VK-X1000 for imaging and profilometry of fillets.

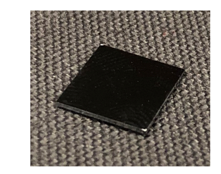


Dispensing system

Materials and Processes

Materials

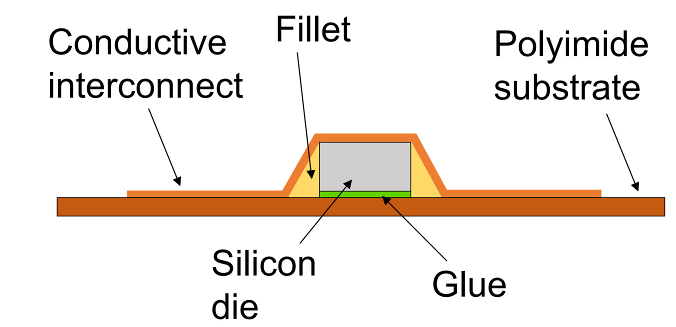
- Substrate
  - UPILEX-50S polyimide (2 mil)
  - 1x1 cm silicon dies glued on substrate
- Inks
  - DuPont 5036 encapsulant to dispense fillets
  - PARU PG-007 to aerosol jet print conductive interconnects over filleted dies
- Needle (for dispensing)
  - 20 Ga plastic tapered

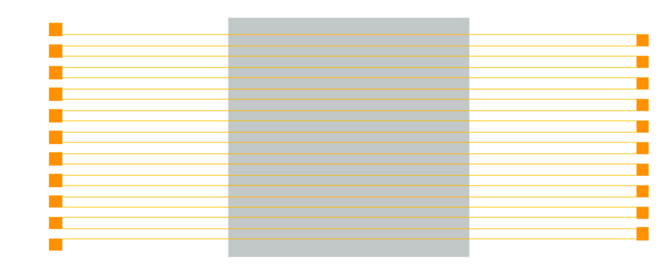


Silicon die

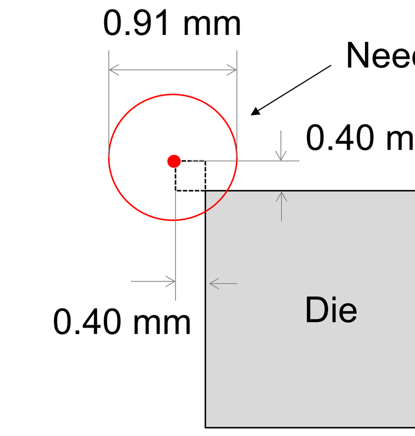
Fabrication Process

1. Dispense fillet around dies
   - Factors of interest are:
     - Dispensing speed
     - Dispensing pressure
     - Number of concentric passes
   - Dispense two layers (cure after each layer is dispensed)
2. Aerosol jet print 20 lines (width = 100 µm) over filleted dies
   - Large number of lines reduces effects of printing variation
   - Die to die difference in average resistance of 20 lines is due to quality of fillet

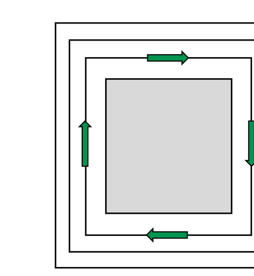




Schematic of conductive lines aerosol jet printed over filleted die



Position of needle vs die



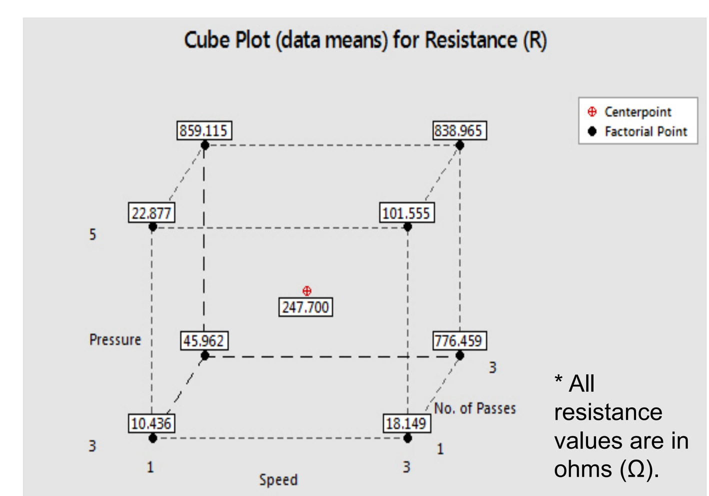
Schematic of concentric passes

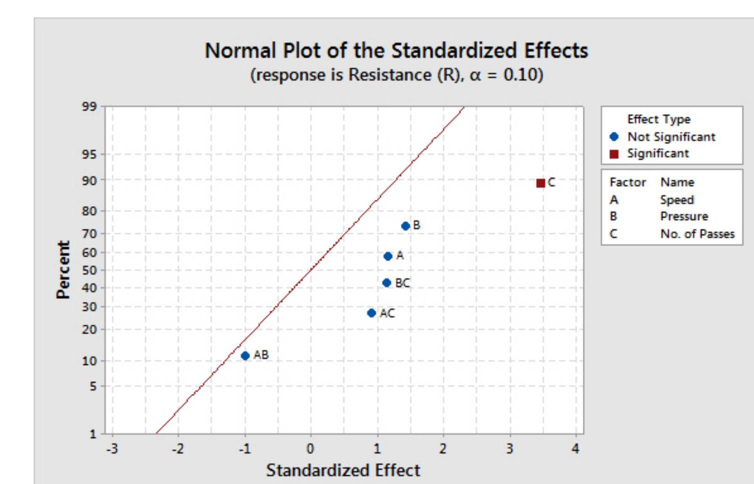
Experimental Design, Analysis and Results

Experimental design: 2^3 with single replicate and two center points.

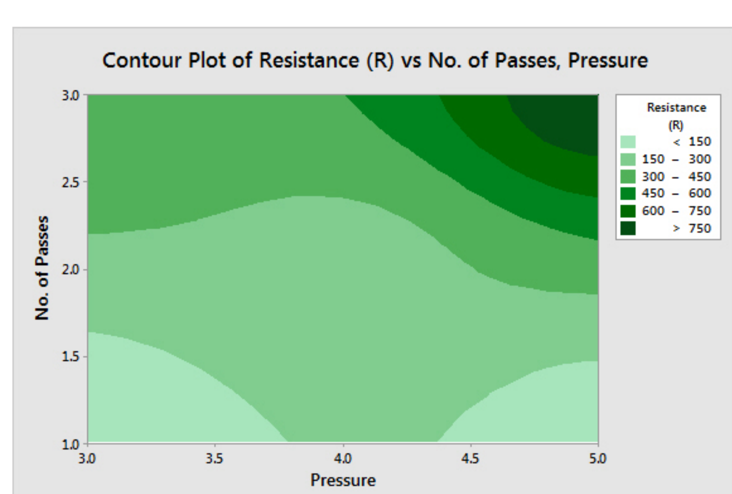
2^3 Design Factors and Levels		Factors		
		Speed (mm/s)	Pressure (psi)	Number of passes
Levels	Low	1	3	1
	High	3	5	3

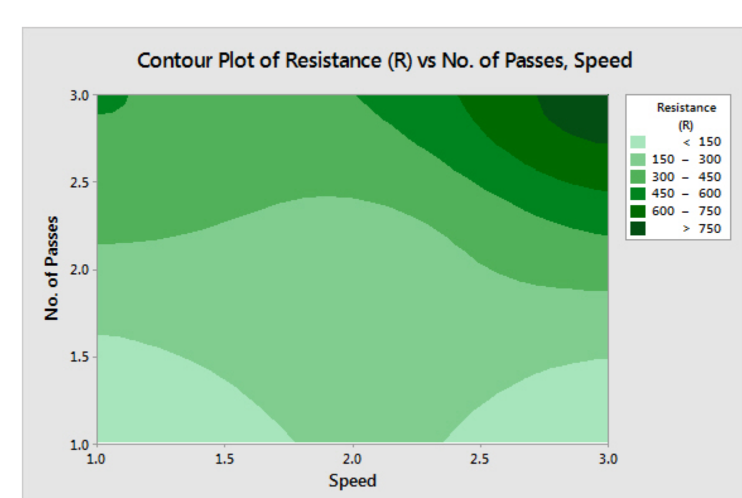
Cube plot summarizes experimental results. Model is refined by excluding three-factor interactions from **ANOVA analysis**. At $\alpha = 10\%$, number of passes is the only significant factor.

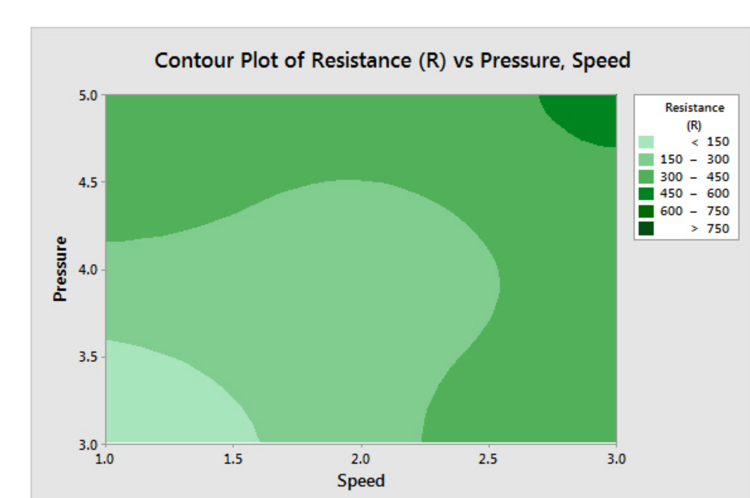




Contour plots allow to visualize optimal combination of dispensing parameters (so that resistance is minimized).



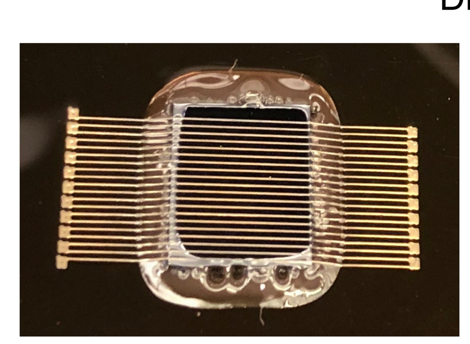


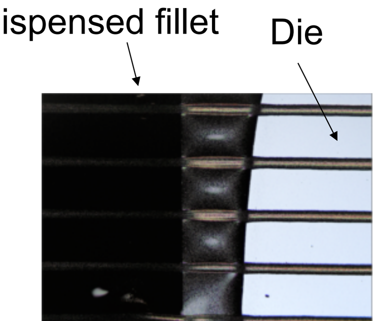


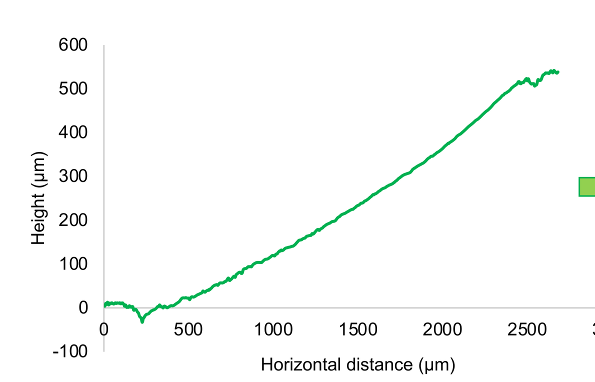
Minimum resistance is achieved with a single pass. Also speed and pressure should be kept at low level.

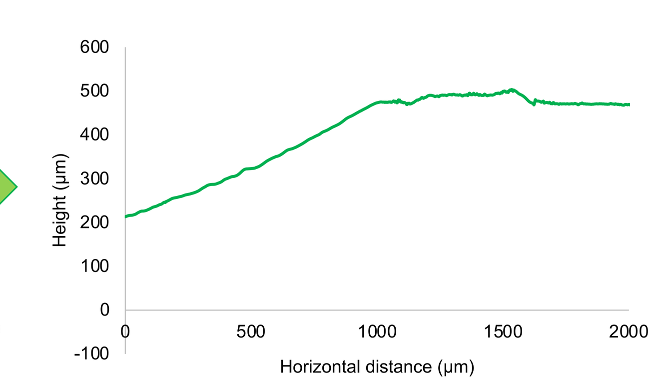
"Very Good" Fillet

- Speed = 1 mm/s (low)
- Pressure = 3 psi (low)
- No Passes = 1 (low)



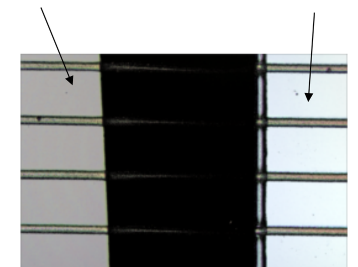


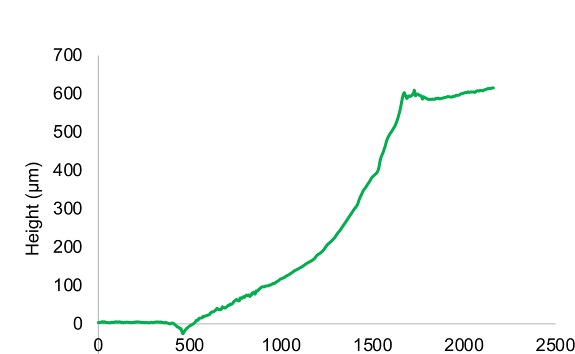




"Good" Fillet

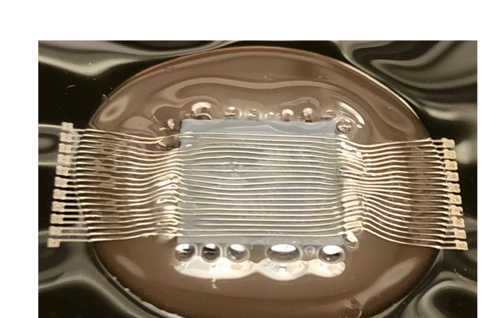
- Speed = 3 mm/s (low)
- Pressure = 3 psi (low)
- No Passes = 1 (low)





"Bad" Fillet

- Speed = 1 mm/s (low)
- Pressure = 5 psi (high)
- No Passes = 3 (high)



Conclusions

- Experimental design
  - 2^3 design with one replicate and two center points
  - Three factors of interest: speed, pressure, number of passes
  - Response: average resistance of aerosol jet printed lines over dies
- Number of passes significantly affects the quality of the fillet at $\alpha = 10\%$
- Optimal dispensing parameters were found
  - Speed = 1 mm/s (low), pressure = 3 psi (low), number of passes = 1 (low)
- Analysis of fillets with laser microscope confirmed statistical results
- Dispensing constitutes a good platform to fabricate smooth fillets between different leveled surfaces

Current and Future Work

Conduct mechanical testing on dies filleted using optimal dispensing parameters

- How does resistance of lines aerosol jet printed over filleted dies change as a result of fatigue cycling?
- What is the role played by the die in the damaging mechanism of the AJP conductive lines?

References

[1] Y. Gu et al., *Advanced Materials Technologies*, 2017.
[2] Y. Gu et al., *Journal of Micromechanics and Microengineering*, 2017.
[3] M. Mengel et al., *Microelectronic Engineering*, 2010.
[4] M. Alhendi et al., *International Symposium on Microelectronics*, 2018.