Ink-Jet Applications, Physics, and Modeling - an Industrial / Applied Research View

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Ink-Jet Microdispensing

Advantages

- Direct-write of materials
  - data-driven (flexible – no masks, low cost)
  - additive (environmentally friendly, low cost)
  - non-contact

- Piezoelectric Ink-Jet Technology
  - single jets and arrays
  - wide operating temperature range (0-370°C)
  - wide range of materials
    - biological, metals, polymers, fluxes …
  - wide range of resolutions
    - 10-120um drops + N drops per spot
  - wide range of rates
    - 1Hz - 1MHz
Solder Jet

Data-Driven
Ink-Jet Microdispensing

- **Applications**
  - Electronics manufacturing
    - interconnects, passives, conductors, dielectrics, adhesives
  - Photonics
    - lens arrays, display materials, waveguides, NLO materials
  - Medical Diagnostics
    - immuno and DNA diagnostics, genomics, proteomics, drug discovery
  - Medical Procedures
    - olfaction, laser surgery, drug delivery, tissue engineering
  - Other
    - pest control, ink-jet printing, combi-chem
Electronics Manufacturing Applications

*Demand Mode Solder Jet™*

Drop Size Modulation: 60 & 100µm drops from same device using different waveforms
Solder Jet
1440 pad microprocessor test vehicle, 60µm bumps
Solder Jet

*Print-on-the-Fly, 100µm bumps, 250µm centers, 400/sec.*
Solder Jet

Model This!

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Poulakakos, Megaridis, Wadvogel

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Printed Solder Interconnects

MEMS Applications – Modeling Challenges

Printed Solder Columns

- Dielectric Layer
- Copper Conductor

60µm towers

3-D structure, 60µm feature size

24µm towers
Electronics Manufacturing Applications

*Embedded Passives*

Conductive Polymer Resistors, <200?/sq, ~1mm long
Photonics Manufacturing Applications

90µm spots and line of phosphor particles

Simulated GRIN lenslet: how is this possible?

100µm waveguides / splitter

light emitting polymer

250µm hemi-elliptical lenses
Photonics Manufacturing Applications
300µm simulated AGRIN lens

- Simulated 300 micron agrin lenslet
- Multidrop / multiple fluid sphere formation with axial (only) gradient. Model this!
Photonics Manufacturing Applications

Solder & microlens on VCSEL: 125μm square pad (solder) 17 μm emitter

Portion of 19,000 300μm lenses printed on glass wafer, for coupling to matching GaAs micro lasers & photodetectors

Array of 80μm spot of optical epoxy doped with fluorescing probe, printed onto 480: m fiber bundle.
Medical Applications

Genetics, Proteomics, Diagnostics

10 fluid ink-jet printhead and printing results (200 µm spacings)

printhead detail (140um grooves)

100um spots of DNA on 200um centers

anti-cytochrome C spots, 40µm in diameter.
Proteomic Analysis

2-D Gel In-Situ Digestion /Analysis on Membrane

Proteome System Ltd.’s Chemical Printer for peptide mass fingerprinting
Olfaction Diagnostics

- Olfactometer
  - Research into early onset of neurodegenerative diseases (e.g. Alzheimer's)
Combinatorial Odor Synthesis

Internet Ready
Ink-Jet Printing

- Microfabricated structures 170um pitch
- Polymer orifice array, 170um pitch
- Real-time drop volume modulation results
- 120 channel printhead with onboard drive electronics
- Printhead in operation

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Modeling Ink-Jet Systems

Difficulties in Systems Models

- Multiple types of mathematical regimes
  - Elliptical, parabolic, and hyperbolic equation sets
  - Moving boundaries, phase change, fluid / structure interaction
- Wide range of time scales in different regimes
  - Sub-microsecond to seconds
- Properties at physical and temporal microscale
  - Dynamic surface tension in microsecond regime
  - Viscosity at MHz shear rates; micron scale particles/cells
  - Microscale piezoelectric properties / uniformity
- Mass removal / separation
- Array systems
  - Cross-talk effects, location of computational boundaries
Modeling Ink-Jet Systems

Drive Electronics (elec. circuits) → Piezoelectric Structure (electrostatics, piezoelectrics, solid mechanics)

Fluid Delivery System (Low Re flow) → Acoustic Energy Transfer Zone (fluid acoustics) → Acoustic Energy Transport (fluid acoustics)

Drop Impact (Low Re flow, + ...) → Drop Formation (Low Re, free surface flow)
Subsystems Modeling

Efficient but Hazardous

Channel Height, um

Pressure

Energy

Droplet Volume

Droplet Velocity

Droplet Momentum

Value Normalized

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Goals of Modeling Efforts

Levels of Modeling Results

- Obtain insight into the physics of the system being modeled
- Determine the effects of specific variables
  - qualitative performance prediction OK
- Determine optimum configuration parameters
  - qualitative performance prediction OK
- Manufacturing materials/process selection
  - qualitative performance prediction OK
- In-process manufacturing test support
  - qualitative performance prediction OK
- Quantitative performance prediction
Orifice Plate Thickness Effects

Maximum Velocity and Frequency

shared wall satellites above 17V for 2 mil thick plate, above 20V for 1 mil thick plate
Agenda

• Industrial Application of Ink-Jet Technology
• Modeling of Ink-Jet Systems
• Modeling in an Industrial Environment
• Case Study: Shared Wall / Shear Mode Printhead
Shared Wall / Shear Mode Printhead

3-D piezoelectric structures (shared wall), 170um pitch

boundary condition: polymer orifice array, 170um pitch

drive waveform: simplest = 5 degrees of freedom

120 channel printhead with onboard drive electronics

printhead in operation

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Shared Wall / Shear Mode Printhead

Basic Structure, Fields, and Motion

- PZT
- Electric Field
- Poling Directions
- Metalization & Bond Line
- Fluid Channel
- Inactive Material
Model Components

*Shared Wall / Shear Mode Printhead*

- **Structural Motion**
  - coupled electric field, piezoelectric, structural
  - static analysis
- **Fluid / Structure Coupling**
  - quasi-static assumption
  - change from pressure / wall position system to pressure rise / compliance
- **Fluid Acoustics**
  - method of characteristics solution
  - frequency dependent friction
- **Boundary Conditions**
  - orifice flow model from steady flow data; SOR
  - manifold pressure from steady flow model
- **Drop Formation Model**
  - various
- **Drop Impact Model**
  - “Spread Factor”
Model Block Diagram

- Structural, Electrical, Piezoelectric Static Solution
- Pressure Rise per Volt
- Compliance
- Waveform (voltage vs. time)
- Inlet Boundary Condition
- Method of Characteristic Solution
- Orifice Flow Model
- Drop Impact Model
- Drop Formation Model
Structural Model

Elements and Mesh Geometry

- unpoled PZT
- PZT
- fluid
- PZT
- Poling Direction
- artificial boundary
- cyclical boundary condition
- metalization & bond line

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Structural Model
Voltage Distribution and Displacement

unpoled PZT

metalization & bond line

PZT

fluid

PZT

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Structural Model
Electric Field Distribution

unpoled PZT

PZT

metalization & bond line

fluid

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Values:
- 6.73E-07
- 1.43E-04
- 2.85E-04
- 4.27E-04
- 5.69E-04
- 7.12E-04
- 8.54E-04
- 9.96E-04
- 1.14E-03
- 1.28E-03
Method of Characteristics Solution

Pressure vs. Time Solution

- Time = 26 us (after voltage fall)
- Time = 63 us (end of waveform)
Orifice Flow Model

Orifice Flow Model and Data

Discharge Coefficient

Reynolds Number

- data
- model
Drop Formation and Impact Models

- Drop formation
  - Method: Adams & Roy
  - Case: solder

- Droplet impact & solidification
  - Method: Poulakakos et al.
  - solder on Si
Fluid System Model

Jet Velocity = 5 m/s

Array Size & Fluid
- 0.25”, IPA
- 1” IPA
- 0.25” ink (4cp)
- 1” ink (4cp)

Pressure Drop

Orifice | Channel | Manifold | Inlet | Line | Filter | TOTAL
---|---|---|---|---|---|---
0.25”, IPA | 1” IPA | 0.25” ink (4cp) | 1” ink (4cp)