

Inkjet Fabrication of Multi-Color Microcup® Electrophoretic Display

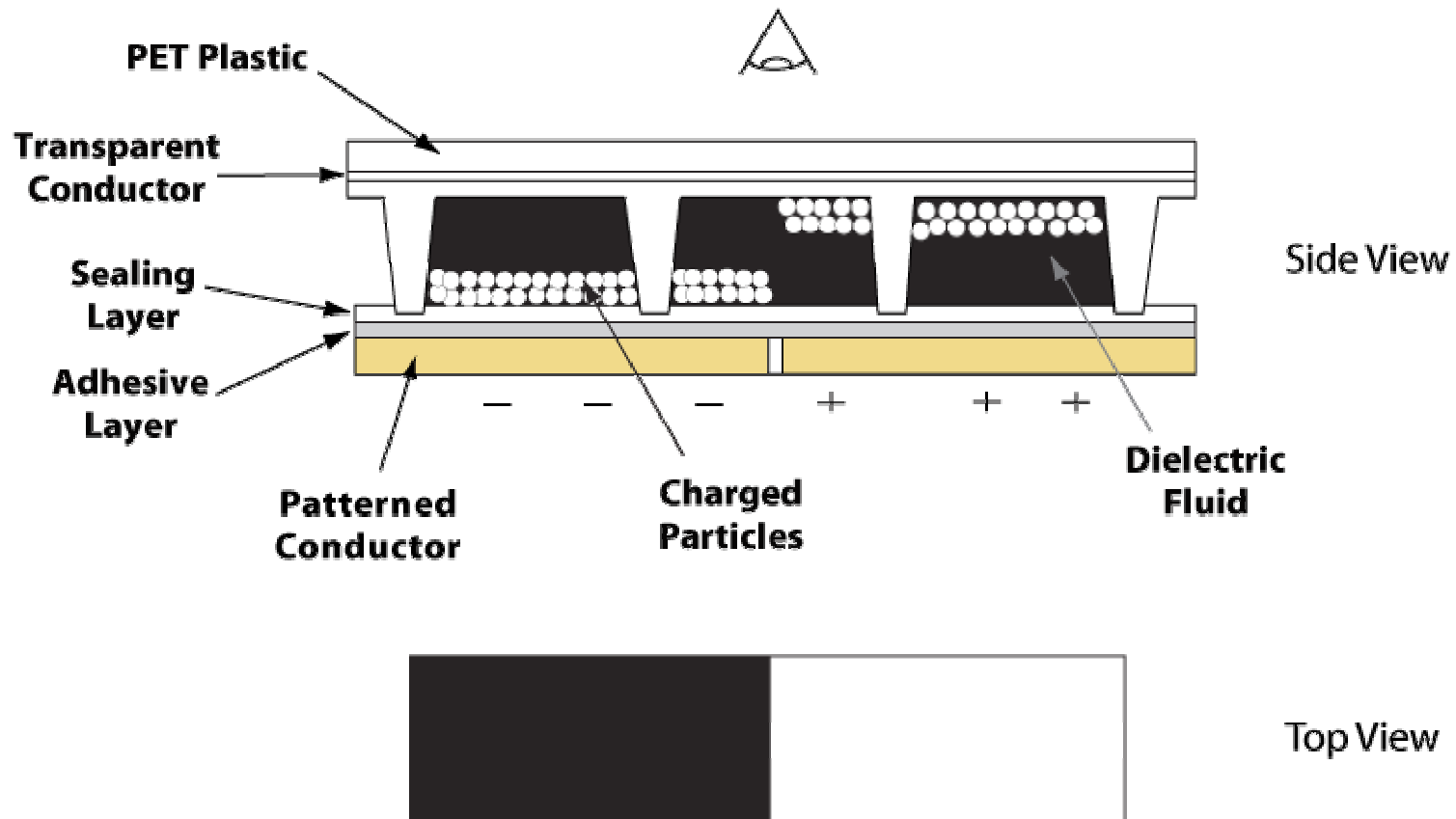
Litrex (Tianzong Xu, Scott Bruner, Michael Hiraoka)

SiPix Imaging (Xiaoja Wang, Peter Li, Deepak Sodhi)

Overview

- EPD Displays
- Inkjet Printing
- Materials
- Inkjet Printing Test
- Results
- Future Work

Microcup® EPD Structure



Bistable! = ↓ Power

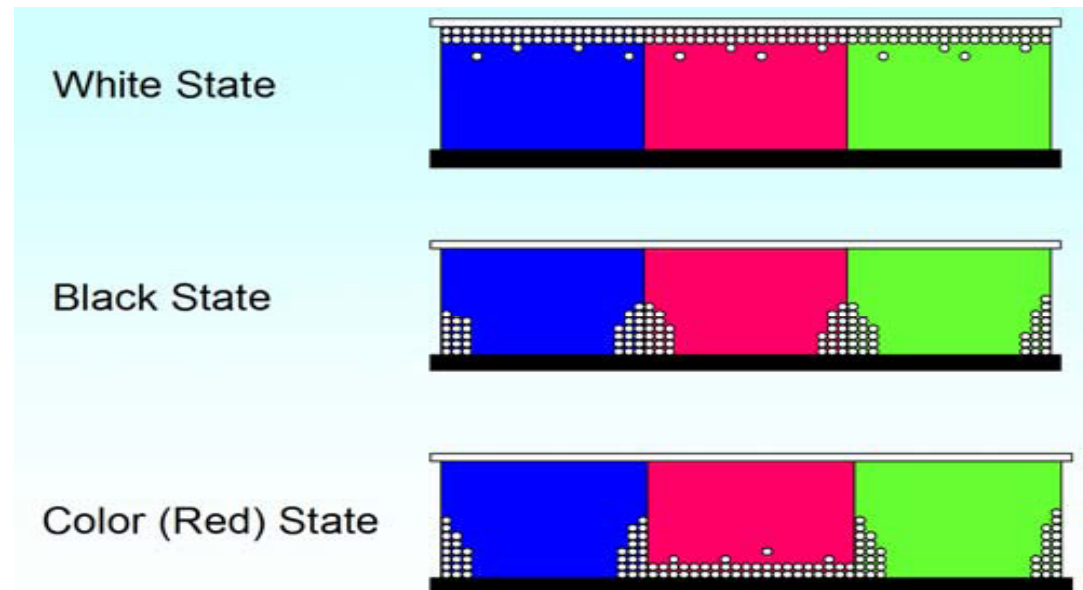
Sectional Color Display

- ❑ Multiple colors
- ❑ Continuous display



Photograph of SiPix Sectional Color Product

Full Color Display



1. Single (White) particle system.
2. RGB dye solution.
3. Black background.
4. In-plane switching TFT

Inkjet Printing in Display Manufacturing

**“Precise, On-Demand Deposition of Material
Accurately on a Patterned Substrate”**



70

- Designed for research and development of ink-jet process and materials
- Maximum substrate size: 200 x 200 mm



120

- Designed for research and development of ink-jet process, materials, and devices
- Maximum substrate size: 370 x 470mm



142

- Production system with robotic interface, factory automation, and remote ink delivery system
- Automatic print head maintenance and ink refill. Maximum substrate size: 370 x 470mm

Inkjet Printing is Scalable to Gen 8 & Beyond!!



Inkjet Printing for Color EPD

- High precision inkjet printing technology has been developed for display manufacturing.
- Critical EPD inkjet printing features
 - Fluid specific
 - Fluid -- Printhead compatibility and fluid handling
 - Flexible substrate specific
 - Resolution and registration
 - Compensation for substrate distortion
 - Compensation for imperfect system components and environmental variation

Material Compatibility to Inkjet Printing

□ Fluid properties

	Viscosity (cps@20°C)	Surface tension (dynes/cm)	Solvent vapor pressure (mmHg@25°C)	Solvent Boiling Point (°C)	Solid Content (wt%)
SiPix ink fluids	1-10	17-20	1-50	≥ 130	< 10%
Typical PZT Inkjet fluids	1-20	20-80	0.1-24	≥100	≤100%

In order to prevent interaction of charged particles with piezoelectric micro-pump, EPD dispersion was separated into two portions: dye fluid and particle dispersion. Inkjet printing of dye fluid is evaluated here.

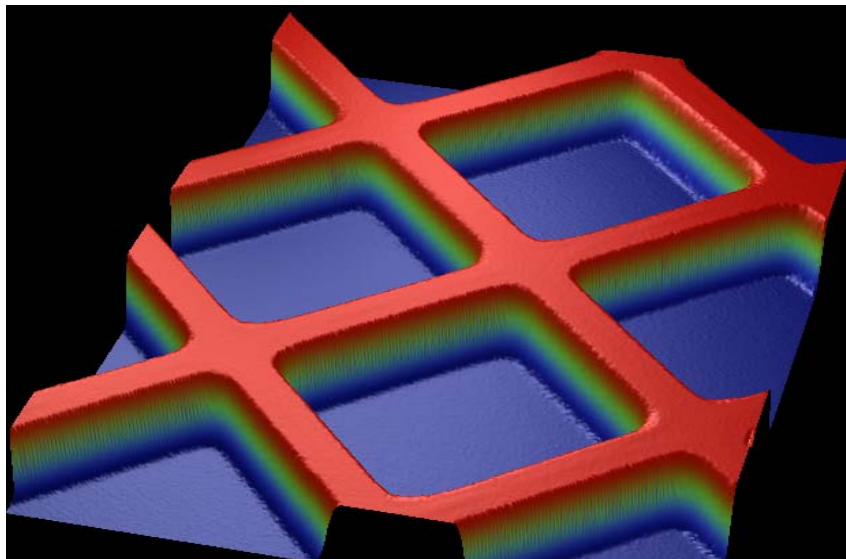
Ink Fluid Jettability

	Solvent vapor pressure (@25°C)	Solvent Boiling Point (°C)	Nozzle clog (%)	Stop-Restart Performance	Gold plated Nozzle-plate flooding
Ink A (Blue)	50 mmHg	135	30%	OK for 1 min stop	severe
Ink B (Dark blue)	50mmHg/ <1 mmHg	135/200	<2%	OK 1 min stop	severe
Ink C (Red)	<1 mmHg	200	<1%	OK 1 min stop	severe

Microcup® Compatibility to Inkjet Printing

Microcup® EPD typical fluid volume: 10pl ~ 1000 pl.

Inkjet printing head typical drop volume: 4pl ~100pl



3-D image of microcups

1. Microcup® forms natural reservoir for colored fluids.
2. Microcup® size and shape can be easily modified.
3. Microcup® and sealing form natural protection to prevent the intermixing of colored fluids.

Substrate Compatibility to Inkjet Printing

□ Impacts of Flexible substrate on printing accuracy

- Drop placement error source identification and compensation technology are critical in inkjet printing.
- Compensation for the thermal expansion of the plastic sheet and the material shrinkage during Microcup® formation is to be considered for pattern accuracy.

□ Error compensation

- Metrology solution for characterizing substrate distortion
- Substrate/printhead alignment and various compensation techniques
- Development of specific compensation techniques for Microcup substrate distortion is continuing

Inks and Substrate

□ Inks

- Red, Green, Blue dye solution
- Organic solvent vehicle

Preparation of inks

- Filtered by 0.45um syringe filters
- No degassing

□ Substrate

- SiPix Microcup® Flex Sheet
- Microcup size: ~ 400 pl

Preparation of substrate

- Used as is. No surface treatment

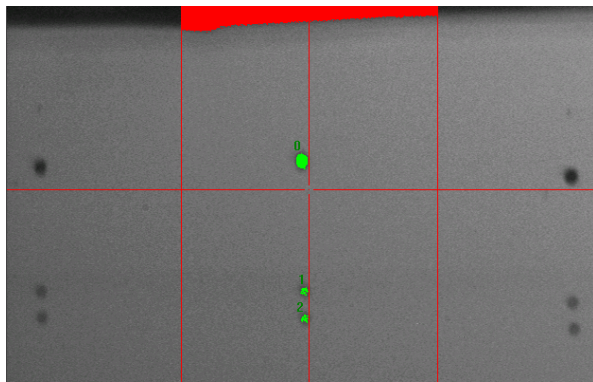
Printing Conditions

- ❑ **Printer: Litrex 80L system with syringe ink supply and manual meniscus pressure adjustment**
- ❑ **Printhead: Dimatix SM-128**
- ❑ **Substrate placement:**
The flex sheet substrate attached onto a flat blank glass plate carrier using low surface tension liquid to minimize flex substrate distortion
- ❑ **Alignment and error compensation:**
Layout adjustment and multiple-swath manual alignment
- ❑ **Standard lab environment: 68-72°F, 30-50% R.H.**
- ❑ **Key process parameters**

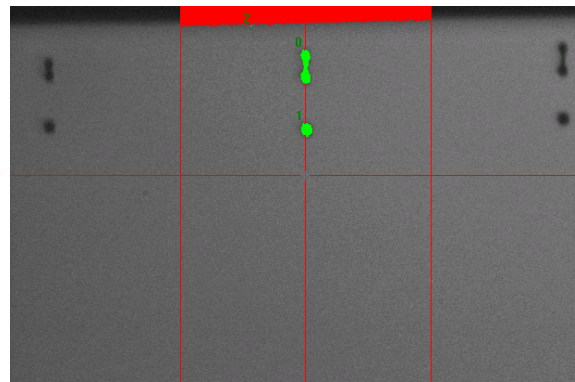
Slopes (V/ μ s)	Jetting Voltage (V)	Pulse width (μ s)	Meniscus Pressure (mm Ink)	Printing Speed (mm/sec)	Drops Per Pixel
40/40~80/80	60 - 100	5 - 10	-40 to -10	10 -20	4 - 8

Jetting of R,G,B Inks

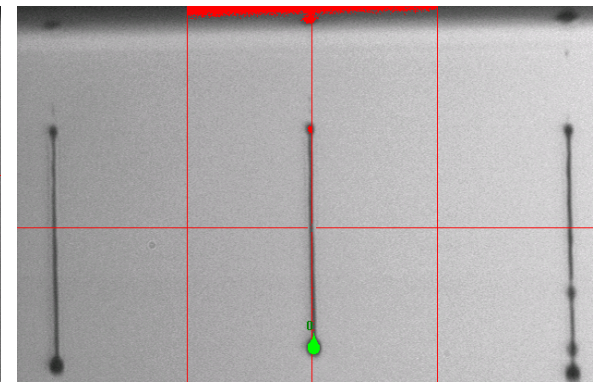
Dimatix SM-128



Red Ink



Green Ink



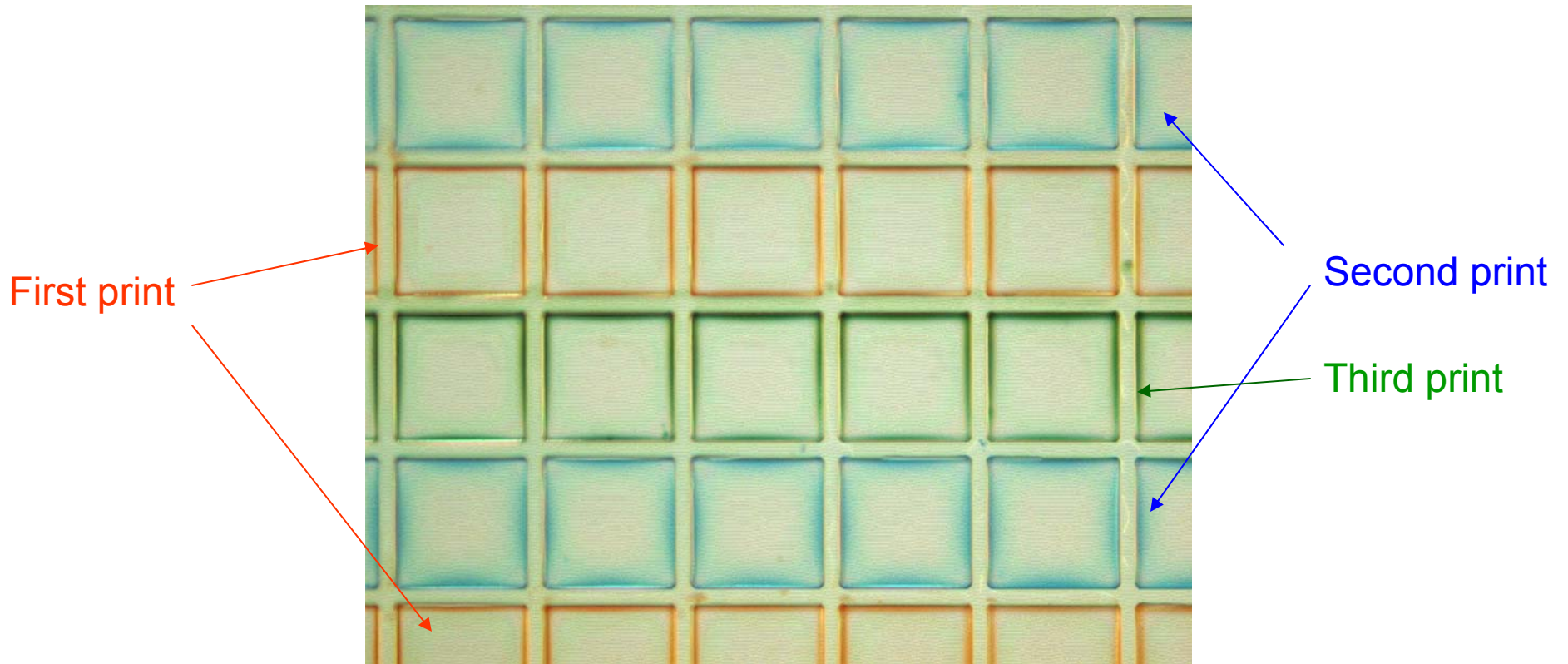
Blue Ink

Jetting conditions: 50/50 – 80/80 V/ μ sec, 60 -100V, 500Hz

Jetting velocity: ~ 4.0 – 5.0 m/sec

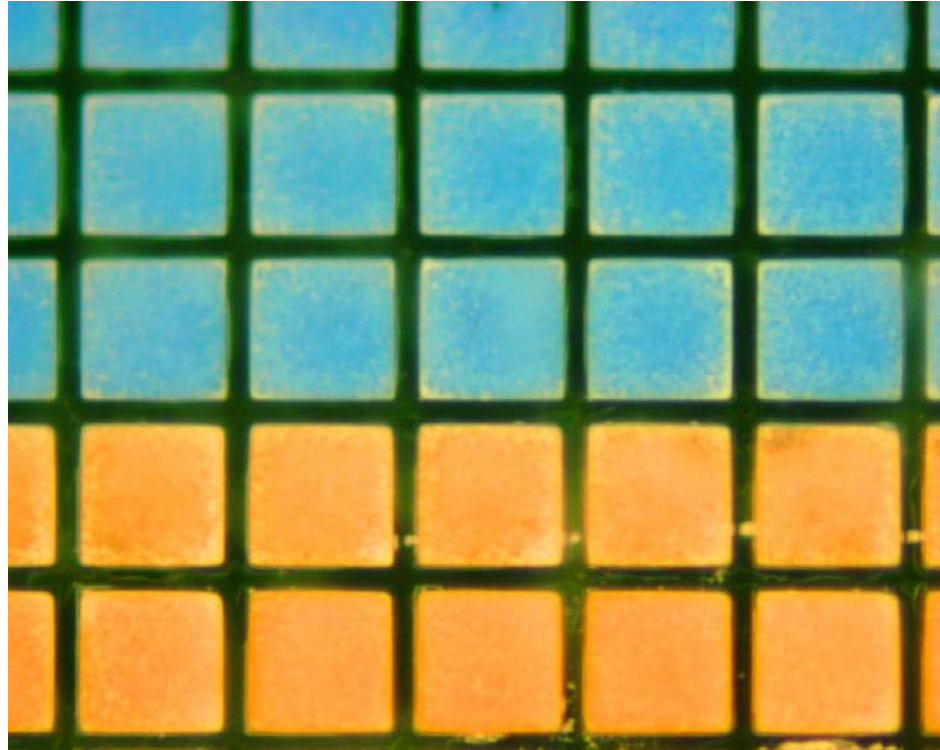
Nominal drop volume: 50 pl

Inkjet Printed RGB Microcups



Optical microscopic image of inkjet printed microcup with alternating RGB strips
(Image was taken after solvent evaporated.)

Printed EPD Film



Optical microscopic image of EPD film with inkjet printed blue and red segments

After dyes were displaced in microcup, EPD particle dispersion was filled and sealed using standard process. Lower optical density as compared to standard product related to dyes, dye concentration and total deposition volume

Ink Issues and Approaches

□ Major issues for the current ink formulation

- Low ink surface tension due to the solvent vehicle used causing lower jetting frequency ($\leq 1.5\text{kHz}$) and head nozzle-plate flooding.
- High vapor pressure of solvent vehicle causing nozzle blocking.

□ Improvement Approaches

- Multiple solvents and/or additional surfactants for ink surface tension adjustment and jettability improvement
- Use of solvents with higher boiling point and lower vapor pressure

Substrate Issues

□ Major issues of the current microcup flex substrate

– Sub-pixel distortion

- Linear distortion: 0.13% ~ 0.2%
- Angular distortion (deviation from 90°): 0.75°~0.79°

– Global distortion

- Overall global distortion variation across the 200mm x300mm flex substrate is within **50μm**
- The distortion variation is mainly affected by the microcup fabrication process, the substrate material mechanical properties, and the substrate handling by the printer.

Substrate Improvement Approaches

□ Substrate Improvement

- *Better substrate material rigidity*
- *Minimum distortion by microcup fabrication*
- *Multiple alignment marks for precise alignment*

□ Distortion Compensation Approaches

- Compensation for linear distortion
 - *Sub-pixel layout adjustment*
 - *Proprietary thermal compensation technique*
- Compensation for angular distortion
 - *Non-orthogonal printing technique in development*
- Compensation for global distortion
 - *Global substrate layout adjustment*
 - *Multi-swath alignment and built-in job-queue printing*

Printhead Issues and Approaches

□ Major issues for the printhead

- Nozzle-plate flooding
- Drop volume variation from nozzle-to-nozzle

□ Improvement Approaches

- *Nozzle-plate with non-wetting coating to eliminate the flooding*
- *Drive-Per-Nozzle™ technology to minimize nozzle-to-nozzle variation*

Prototype Printing Issues and Approaches

□ Major issues for the printing system

- Non-optimized meniscus pressure setting
- Limitation on the microcup angular distortion compensation

□ Improvement Approaches

- Litrex 70 & and120 Lab systems and Litrex 142 Production system have more precise control of meniscus pressure
- Non-orthogonal printing technique is under development to address the microcup angular distortion