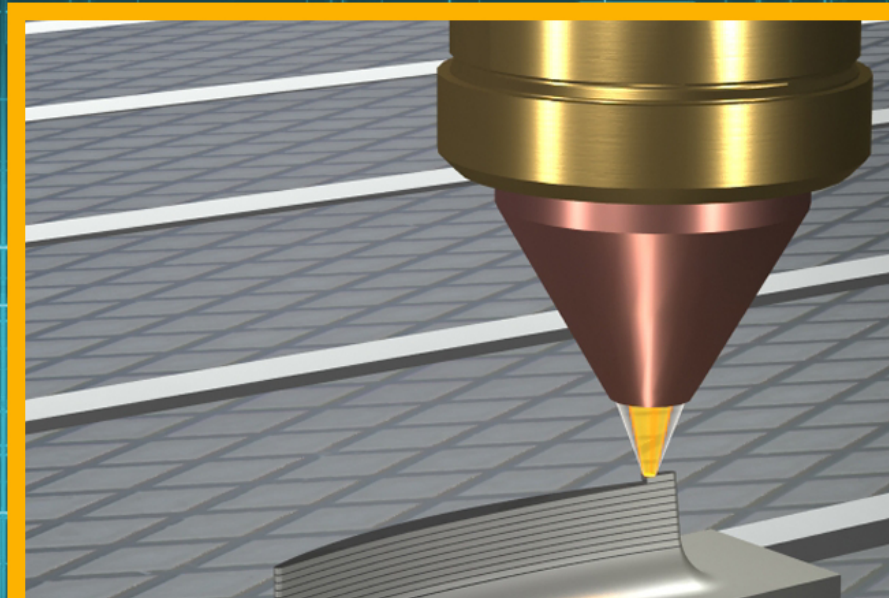


# Additive Manufacturing of electrical Functionalities

Dr. Ines Dani, Fraunhofer IWS Dresden

November 12 – 13, 2014, Dresden



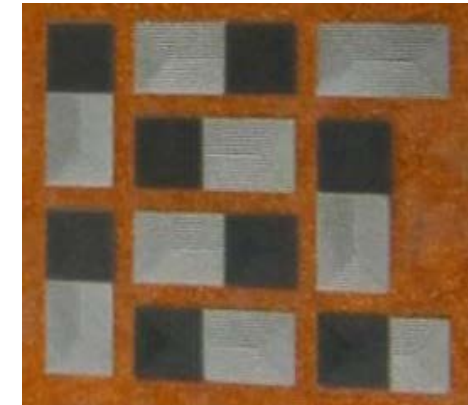
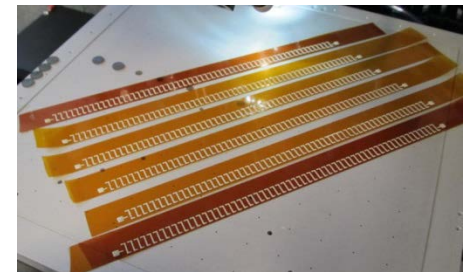
**INTERNATIONAL SYMPOSIUM »ADDITIVE MANUFACTURING«**  
Dresden, February 25 – 26, 2015



# Additive Manufacturing of electrical Functionalities

## Overview

- Why?
- How?
- What?
  - conductors
  - thermoelectric generators
- Summary / Vision



# Motivation

- additive manufacturing technologies enable new, unique capabilities
- embedding of electrical functionalities (e.g. conductors, sensors, actuators, energy harvesters & storage)
- deposit conductive materials during fabrication  $\Rightarrow$  simplification of manufacturing process for functional devices
- processing of 3D substrates  $\Rightarrow$  form-follows-function approach



Simplified, cost efficient manufacturing of electrical functionalities  
by modern printing technologies

# Printing processes for electrical functionalization

printing method determined by requirements concerning

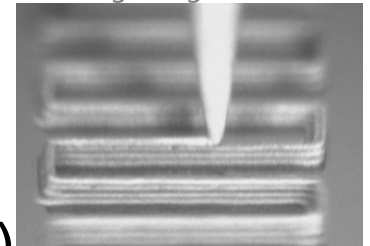
- properties of printed materials
- geometry of substrate (2D / 3D, sheet / roll-to-roll)
- necessary throughput
- printing quality
- economic considerations

dominant for industrial printed electronics

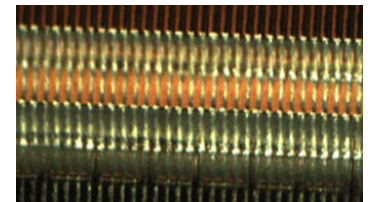
- screen printing
- inkjet printing



gizmag 2013



MIT Technol. Rev. 2013



Optomec



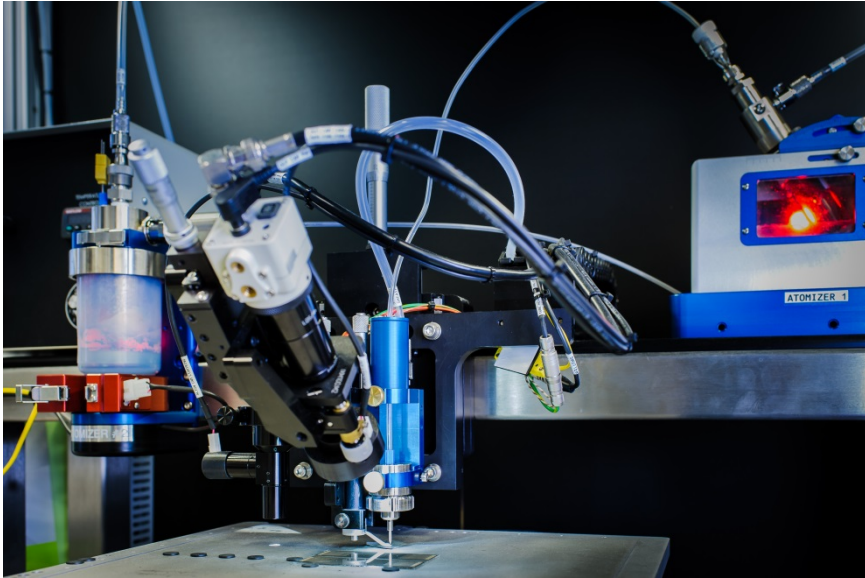
KSG Leiterplatten GmbH

# Printing technologies for electrical functionalities

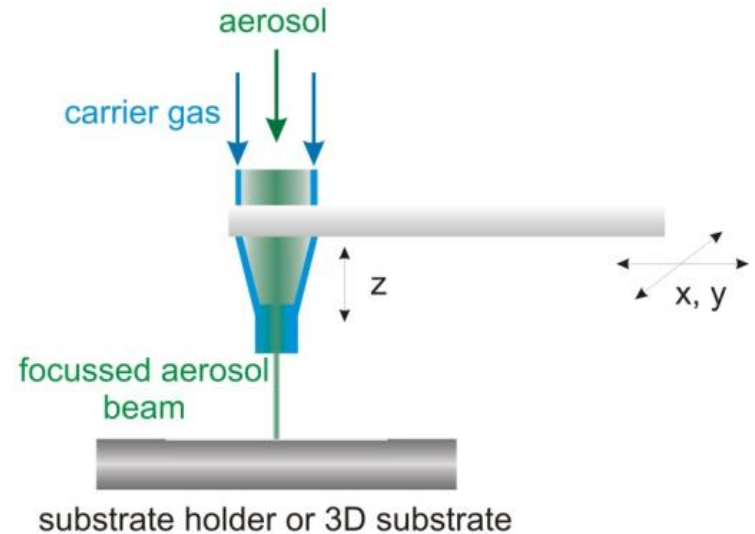
|                    | <b>offset<br/>printing</b>                    | <b>gravure /<br/>flexo<br/>printing</b> | <b>screen<br/>printing</b> | <b>inkjet<br/>printing</b>        | <b>aerosol<br/>Jet<br/>printing</b> | <b>dispenser<br/>printing</b> |
|--------------------|-----------------------------------------------|-----------------------------------------|----------------------------|-----------------------------------|-------------------------------------|-------------------------------|
| advantages         | R2R                                           | R2R                                     | versatile,<br>simple, R2R  | flexible and<br>versatile,<br>R2R | 2D, 3D<br>substrates                | 2D, 3D<br>substrates          |
| drawbacks          | master necessary, contact to<br>substrate, 2D |                                         |                            | max.<br>particle size             | low<br>throughput                   | structure<br>width            |
| throughput         | ≤15 m/s                                       | ≤13 m/s                                 | 100 mm/s                   | ≤500 mm/s                         | 200 mm/s                            | 500 mm/s                      |
| structure<br>width | <20 μm                                        | <20 μm                                  | ≥40 μm                     | ≥ 20 μm                           | ≥10 μm                              | ≥150 μm                       |
| ink/paste          | 40...100<br>Pa s                              | 0.05...0.5<br>Pa s                      | 0.05...100<br>Pa s         | 0.001...0.02<br>Pa s              | ≤ 1 Pa s                            | ≤1000 Pa s                    |

# Printing processes at Fraunhofer IWS

## Aerosol-jet-printing of filigree structures



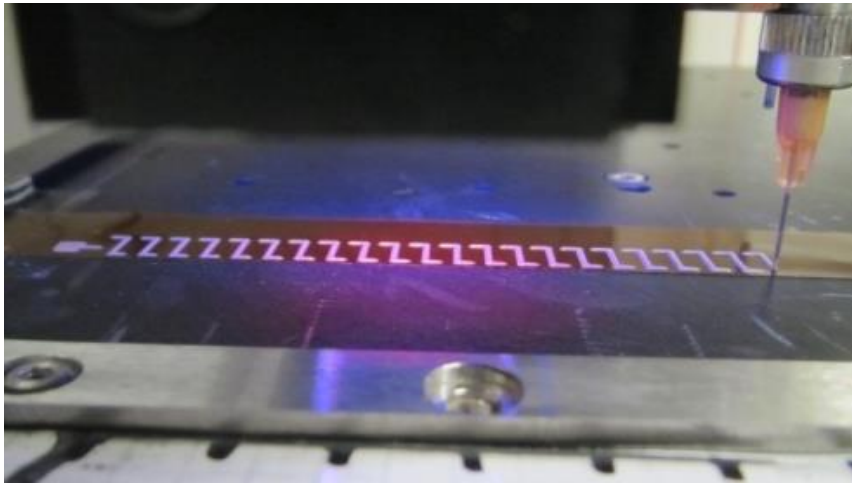
Aerosoljet CE 300 System (Optomec)



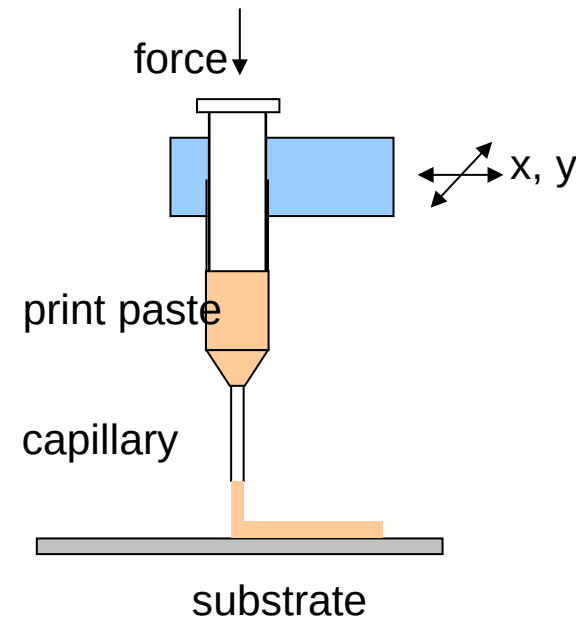
- line width:  $\geq 10 \mu\text{m}$
- precision:  $1 \mu\text{m}$
- distance nozzle-substrate:  $2 \dots 5 \text{ mm}$
- substrate temperature:  $\leq 150^\circ\text{C}$

# Printing processes at Fraunhofer IWS

## Dispenser printing of electronic parts



Dispense Mate D-583 (Nordson Asymtek)



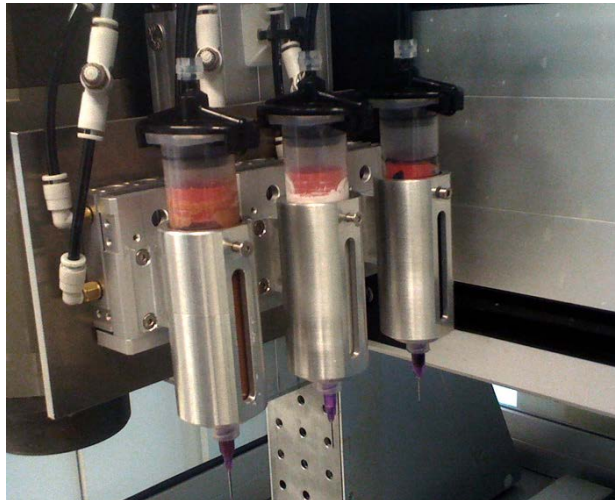
- line width:  $\geq 150 \mu\text{m}$
- precision:  $\pm 25 \mu\text{m}$
- substrate temperature:  $25^\circ\text{C}$
- substrate size:  $325 \times 270 \text{ mm}^2$

# Printing processes at Fraunhofer IWS

## Multi-material dispenser printing

ISEL-GV 4433 (GESIM)

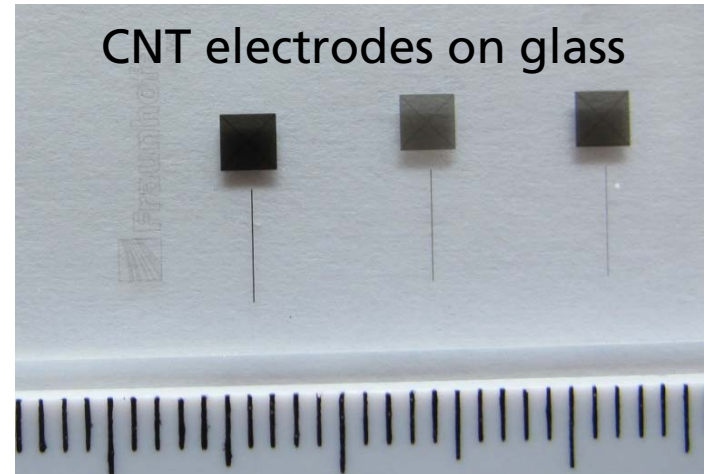
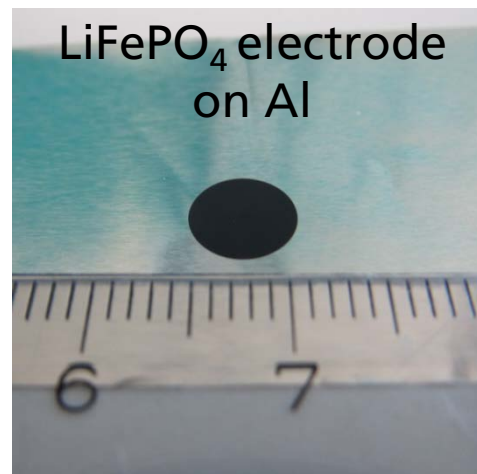
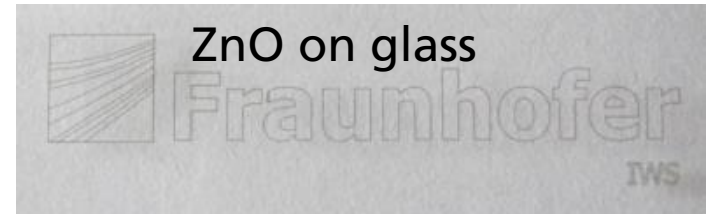
- Substrate size: 200 x 250 mm<sup>2</sup>
- Substrate temperature: 25°C



# Applications

## Conductors and more

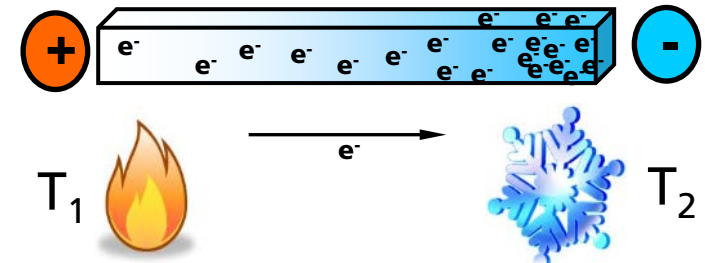
- heating paths from silver, carbon nanotubes (CNT), zinc oxide
- battery electrodes
- antennas from silver and carbon nanotubes



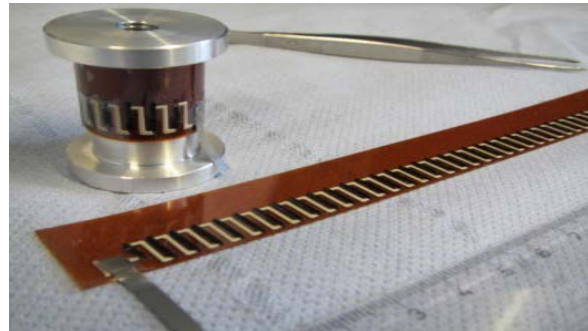
# Applications

## Thermoelectrics

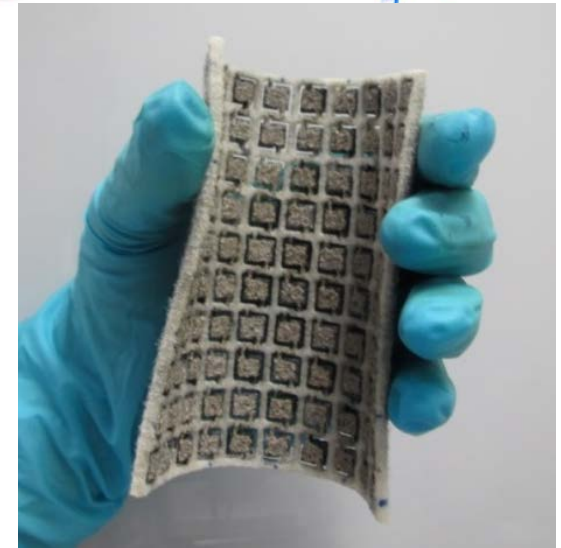
- substrates: polyimide film, non-woven textiles, sponges
- contact material: silver paste
- active thermoelectric material
  - PEDOT:PSS, PEDOT:tos (p-type)
  - Poly[K<sub>x</sub>(Ni-ett)] (n-type)



stacked



rolled

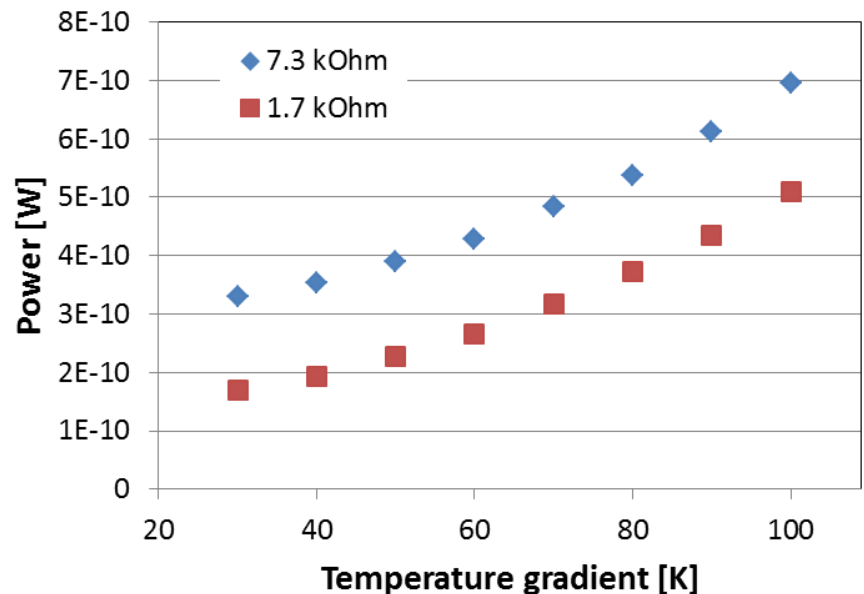
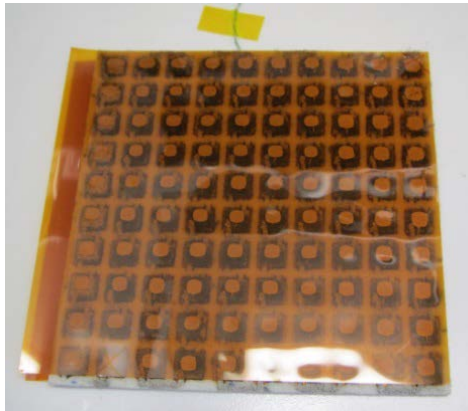


non-woven substrate

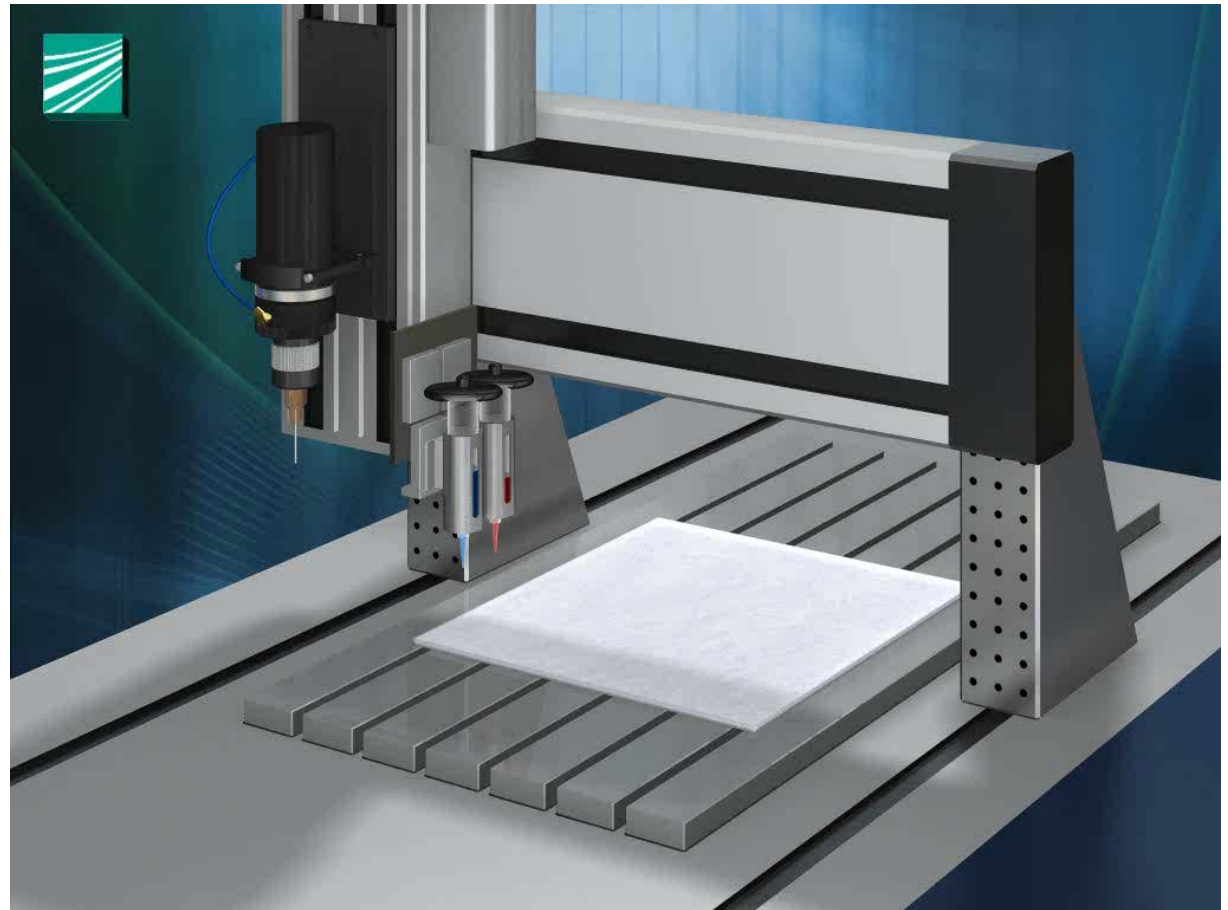
# Applications

## Thermoelectrics

- first working flexible thermoelectric generator on non-woven substrate
- p- and n-type polymer
- 8 thermoelectric couples
- 70 nW at 100 K ( $3.24 \text{ nW/cm}^2$ )



# Vision: Continuous manufacturing of flexible thermoelectric generators



# Many thanks to the IWS printing team

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**Thank you for your attention!**

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