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Microstructured Arrayed Microfluidic Waveguide Structure for Infrared Radiation Focusing and Transfer

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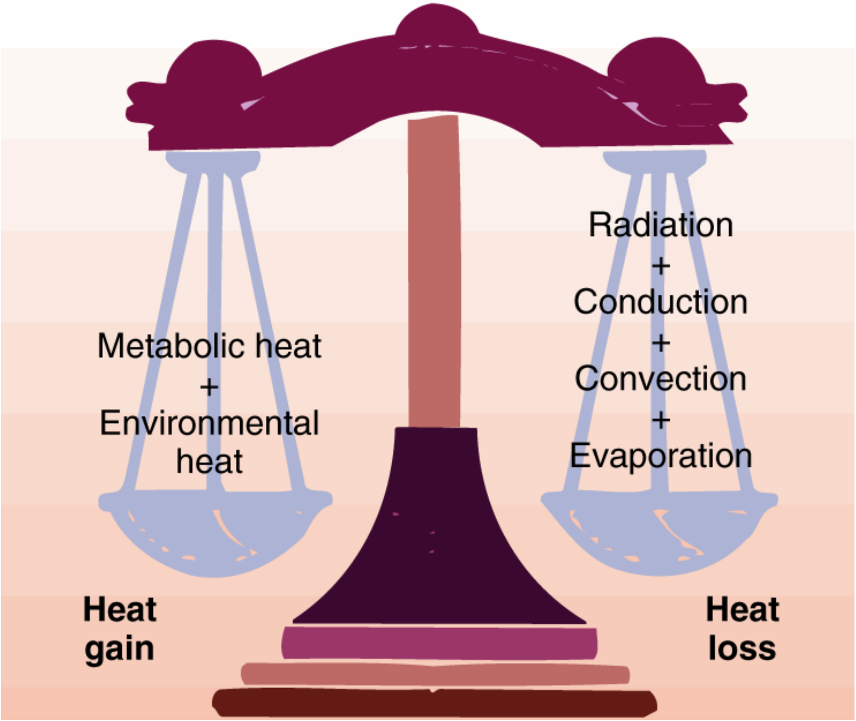
Outline

- **Background**
  - Body heat transfer methods
  - Heat transfer fabrics – impacts
  - Rationale of the interdisciplinary research
- **Existing Heat Transfer Technologies**
- **Our Approach**
  - Micro-structured arrayed micro-fluidic waveguide
  - Fabrication challenges
- **Future Work**

Background: Body Heat Balance

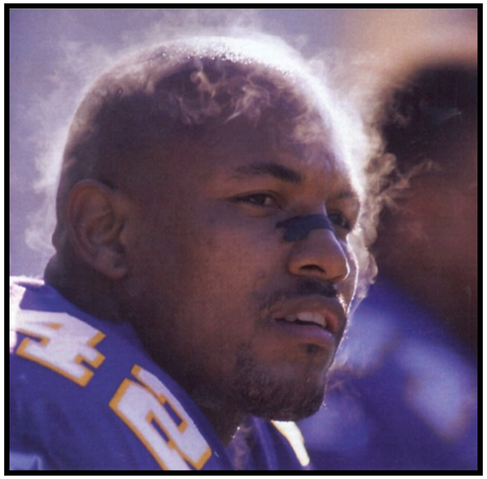
- **Radiation**: heat radiates out of the skin if air around us is cooler than our body
- **Conduction**: transfer of heat by direct contact between body & other objects
- **Convection**: moving air cools us down
- **Evaporation** of perspiration from the skin

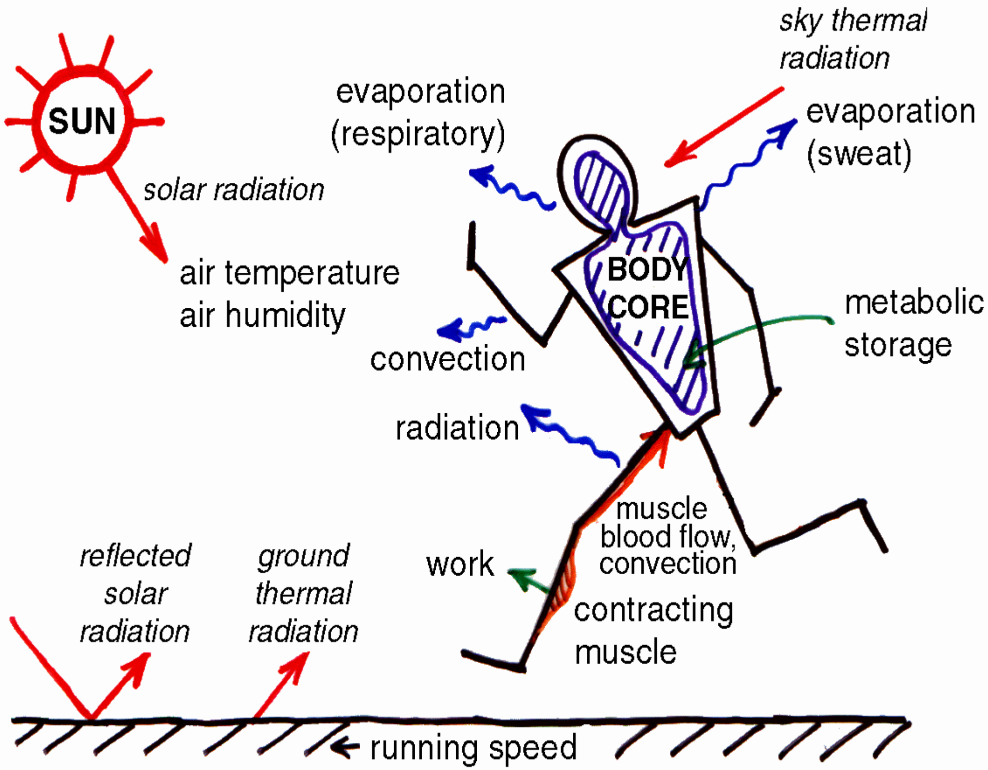


- Under resting thermoneutral conditions (i.e., 18–22°C), ~90 Watts of metabolic heat energy is both produced and removed from body through radiative heat loss in infrared region spectrum.
- Under these conditions, heat transfer is balanced, and a homeostatic life-sustaining core body temperature of about 37°C is maintained.

Background

- However, at 30°C ⇒
  - Radiative heat loss drops to ~ 45 W ⇒ Heat Gain ⇒ Body Temperature Increases





- Conventional efficient heat removal mechanism of sweat evaporation
  - 630 Watts of heat energy over a one hour period.

- Works efficiently to control body temperature under conditions conducive to evaporation

Conditions that limit sweat evaporation

- High environmental humidity (high vapour pressure)
  - eg. Tropics
- When clothing forms a barrier separating skin from surrounding environment
- Aging - sweat rate is lower
- Can lead to a situation known as *uncompensatable heat stress*

  $\Rightarrow$ core body temperature to rise uncontrollably
- A core temperature rise of only 1°C above normal is uncomfortable, causes dehydration due to sweating, and lowers physical work capacity

Sustained body temperatures of more than 5°C above normal are fatal

Heat Removal Problem

- Heat removal problem affects several important occupations, including:
  - Fire service
  - Defence
  - Mining industry

- Require a workforce to wear protective clothing not conducive to sweat evaporation

- Australian Bureau of Transport and Regional Economic report:
  - ***"a significant breakthrough in reducing heat strain while wearing (protective) clothing in field conditions is needed"***

The creation of a practical heat removal device for these workers has challenged scientists to date

Efficient heat removal is needed

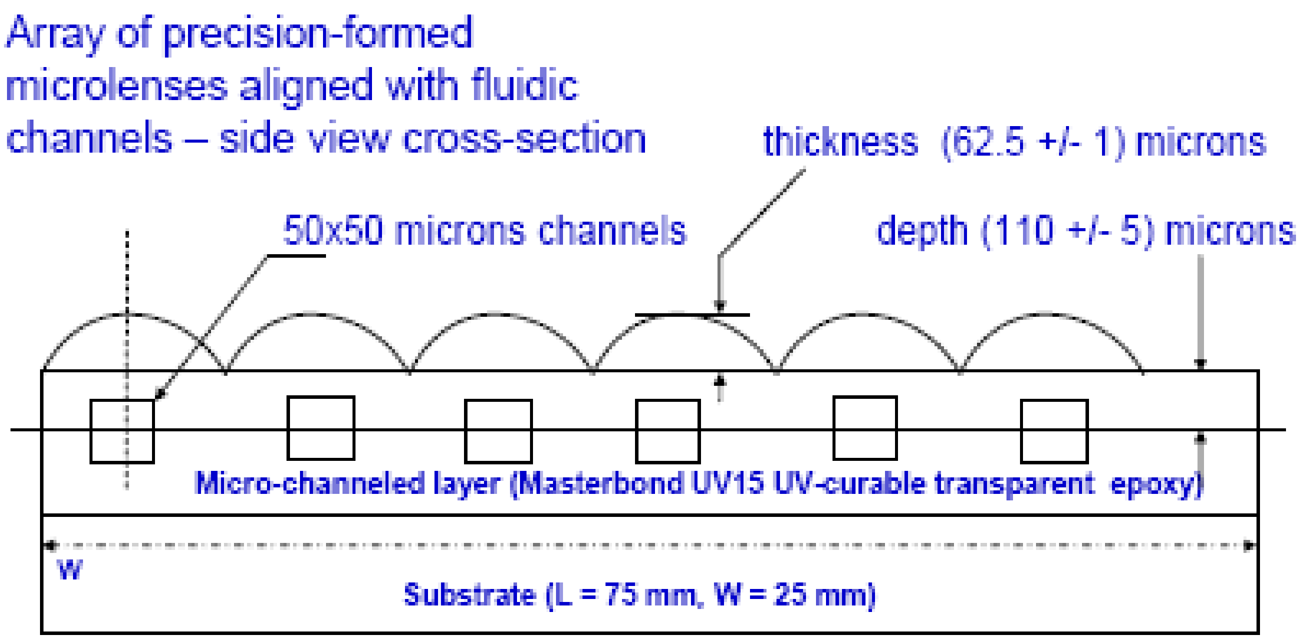
- The radiation emitted by the human body at the mid-infrared wavelength during heavy exercise can be seen as a bright “light bulb”, emitting tens of Watts of invisible light

- Body heat removal could be assisted by concentrating the emitted infrared radiation for absorption on a liquid medium moving within a textile material

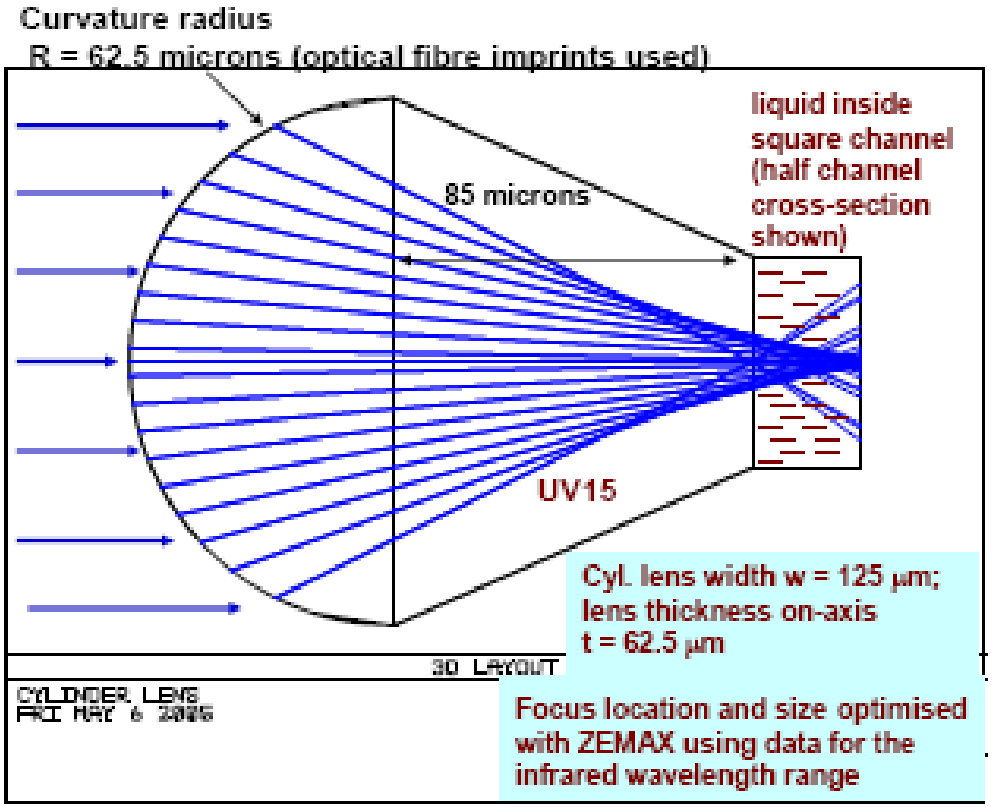
High heat removal efficiency could be possible through the combined technologies of microfluidics and optics.

Microstructured Arrayed Microfluidic Waveguide Structure Design

- Cylindrical microlens array focuses IR radiation onto arrayed microfluidic channels etched onto an epoxy layer deposited on top of the 75mm×25mm substrate.
- Removal of heat is assisted by concentrating emitted IR radiation for absorption on a liquid medium moving through the arrayed microfluidic channels.
- Key feature: High degree of alignment ⇒ maximise absorption of IR energy within moving fluid
- Thermoelectric cooler (TEC) with a heat sink used for cooling circulating fluid
- Cross-section of microfluidic channels and cooling power required are optimised by maximising IR radiation focused at different positions along the fluid flow



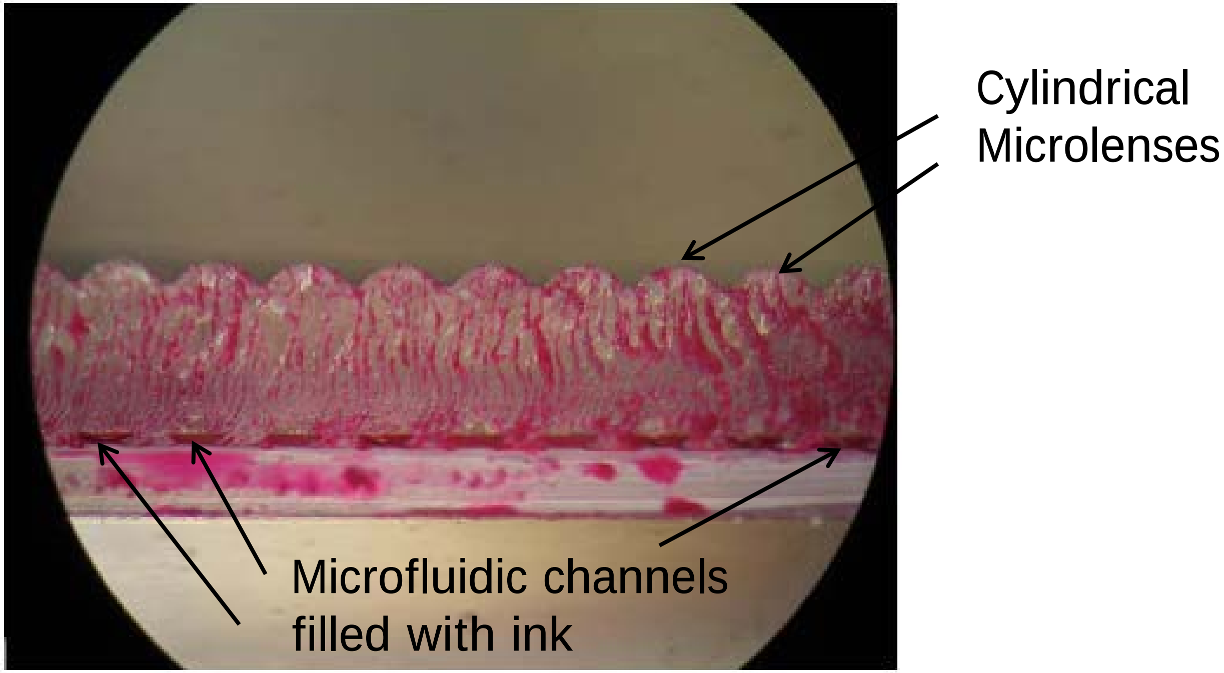
Microfluidic Waveguide Structure Design



- Optical parameters of the fabric optimised using ZEMAX optical design software to achieve the high efficiency of heat capture through focussing and fluid absorption of the IR radiation
- >50% of IR could be absorbed within microfluidic channels

Fabrication results

- Imprint moulding and epoxy re-flow technologies were used
- Principal challenge: a good degree of optical alignment and lens surface quality
- Fabric prototype made of NOA73 adhesive using reflow technology
- Re-flow microfabrication process based on
  - Formation of cylindrical lenses by melting
  - Re-solidifying the solid-phase rectangular microstripes of adhesive material (NOA73) arranged on an optical substrate

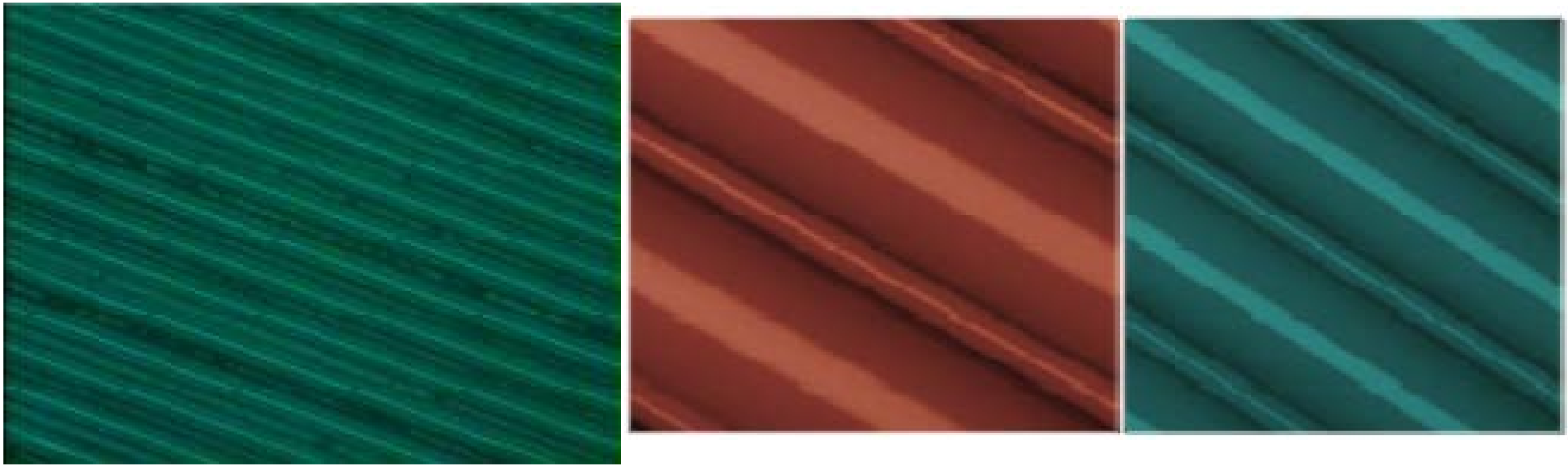


- Initial Fabrication demonstrated the proof-of-concept of microfluidic fabric patch

Optical Quality Inspection

- Cylindrical microlens surfaces inspected under microscope:
  - Excellent surface features
  - Good degree of microlens array alignment

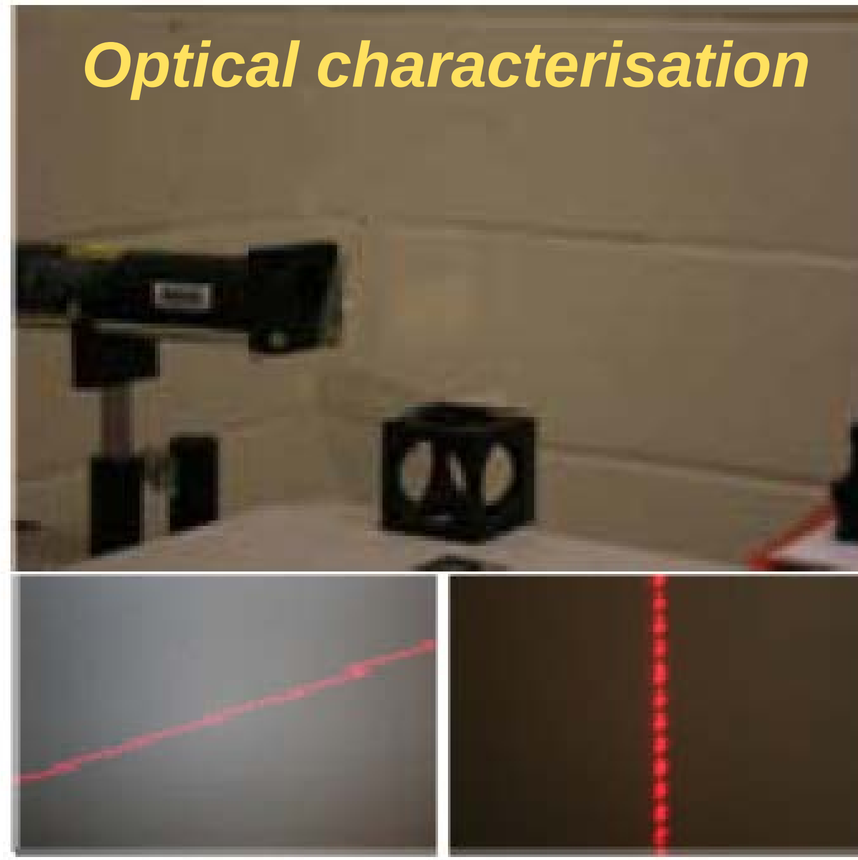
Microscopy characterisation



optical fibre imprints using UV15 epoxy as a base material

Optical Quality Inspection

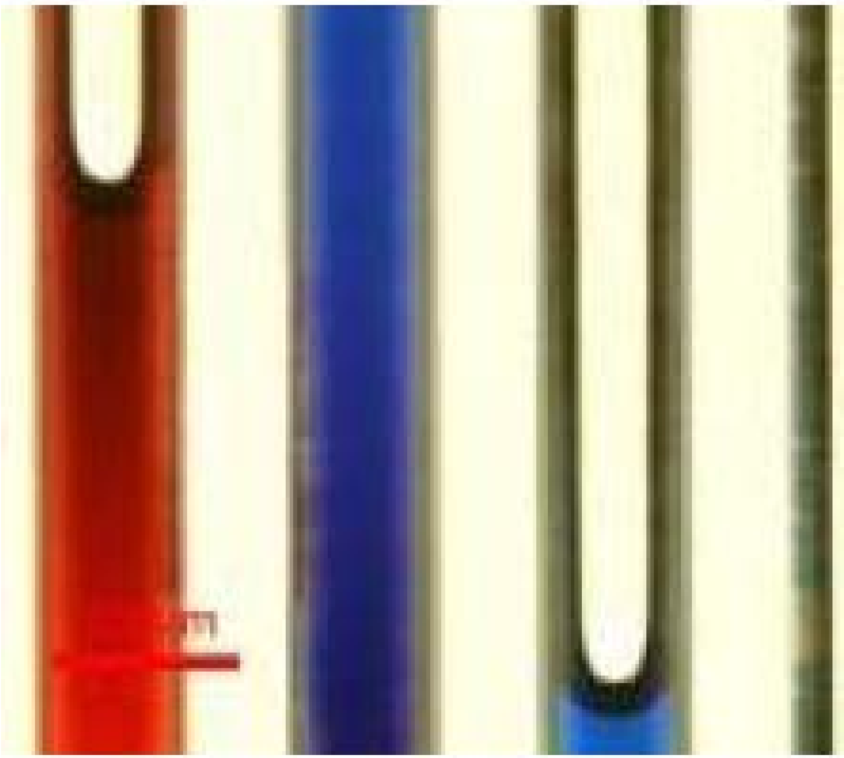
- Diffraction pattern generated by microlens array under the He-Ne laser illumination
  - Excellent lens surface quality
  - Accurate curvature
  - Excellent periodicity of array
  - Alignment/parallelism, lateral spacing uniformity



- Suitability of adopted technology to fabricate high-quality heat-focusing cylindrical lens arrays demonstrated

Fluid Flow Inspection

Microphotograph of ink solutions propagating through the microstructured arrayed microfluidic waveguide prototype

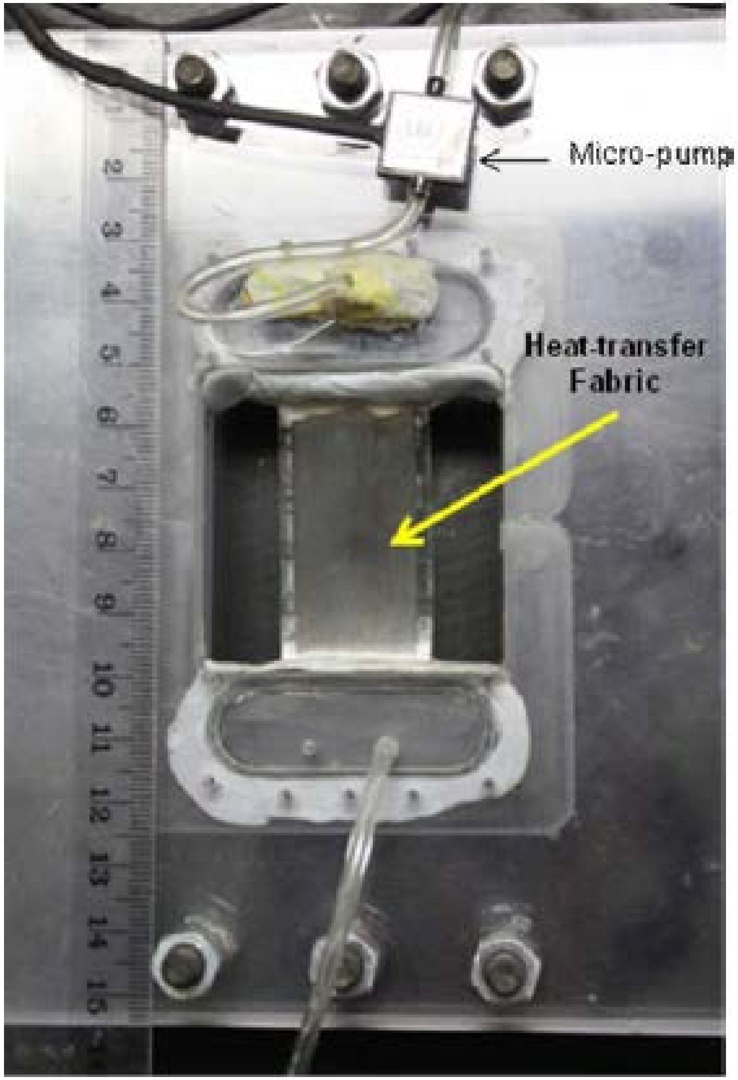


- Ink flows within through the microfluidic channels observed

⇒ suitability of the reflow technology to fabricate microfluidic channels for heat transfer

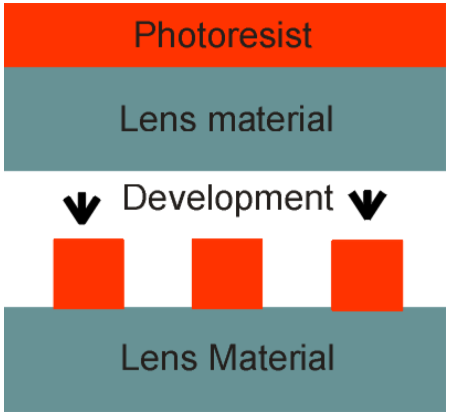
Assembly & Future Work

- Prototype is being tested using a USB-driven micropump
- Pumping arrangement is being optimised
- Thermodynamic characterisation is ongoing
- Viable mass production process is being investigated



Thank You

Reflow Process



After Reflow