Eco-Intelligent Manufacturing

The Eco-Factory Grand Challenge – GC2.3

PRESENTED BY

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Centre for SMART, Loughborough University

03/12/2015

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Webinar Contents

- Introduction to eco-intelligent manufacturing
- Grand Challenge 2.3 Project Update + additional funded projects
- Clean-in-Place
- High Speed, Energy Efficient Manufacturing of Photovoltaics

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Decision Making

- The cognitive process resulting in the selection of a course of action among several alternative possibilities

Current tools:

1. Flow of materials,
2. Flow of costs
3. Flow of information

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Eco-Intelligent Decision Making

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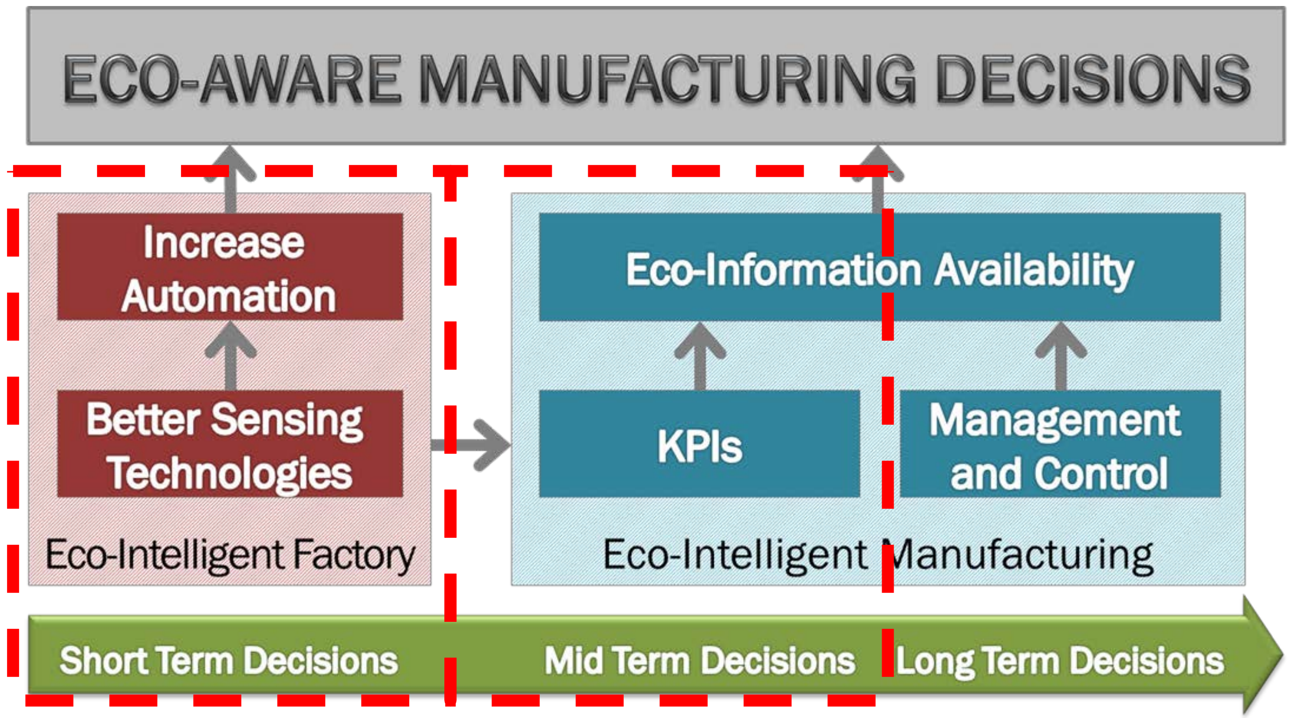
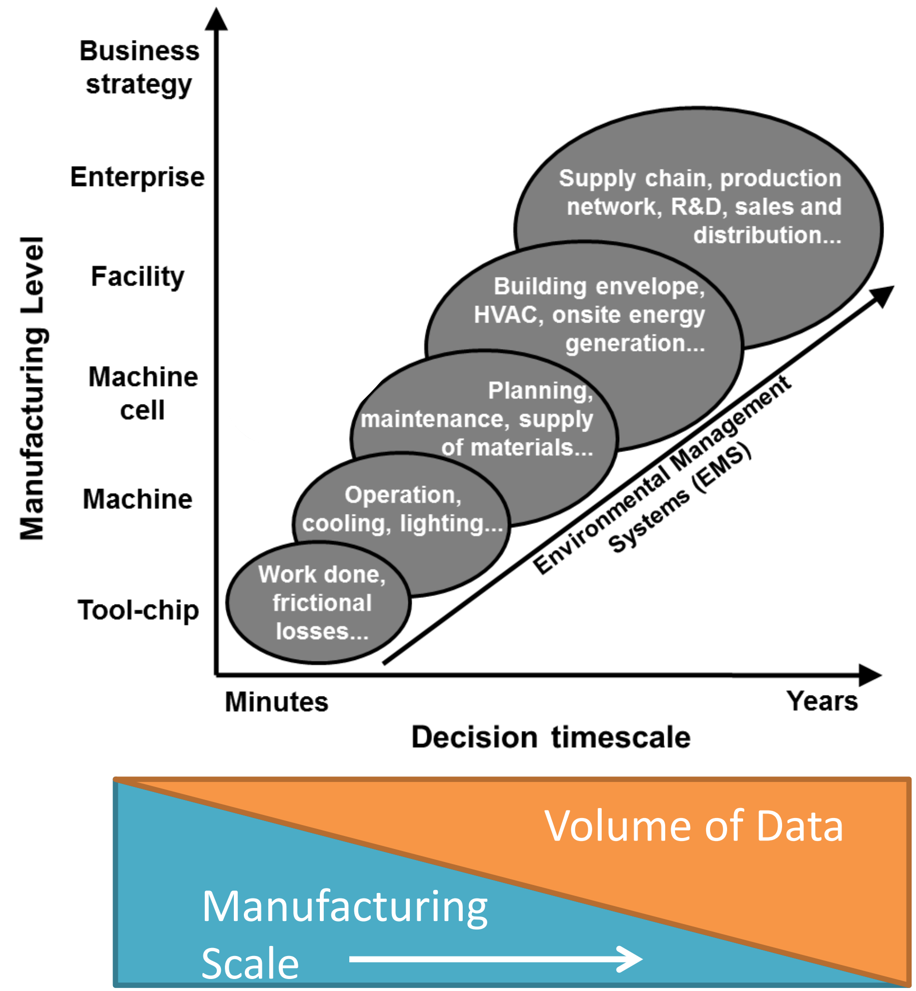
- Extend scope of current manufacturing decision making, incorporating:
  - Environmental considerations
  - Intelligent techniques (artificial intelligence, neural networks, machine learning)



Three decision making timescales:

1. process control,
2. tactical and
3. strategic planning.

Eco-Intelligent Decision Making



Process Monitoring Approach

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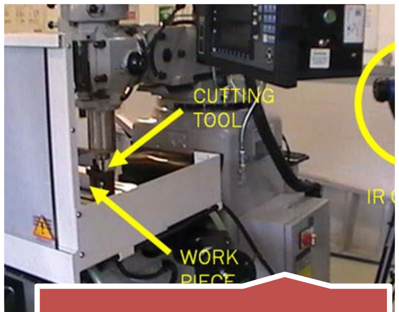
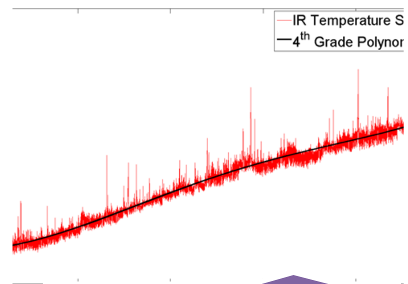
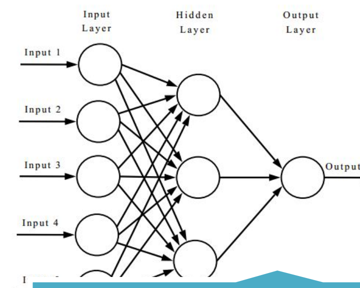


Process Variables

Sensorial Perception



Data Processing



Cognitive Decision Making

- Dynamometers
- Acoustic Emission
- Accelerometers
- Power and current sensors
- Image Acquisition
  - High Speed Camera
  - Infrared Camera

- Statistical
- Time Domain
- Frequency Domain

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Project Update

- GC2.3 Project July 2013 - July 2016 (£311k)
- Body of 8 projects
- IR Monitoring → Enterprise level energy management

- £285k EPSRC Feasibility fund for High Speed, Energy Efficient Manufacturing of Cadmium Telluride Solar Cells
- January 2015 – July 2016

- ~£150k Innovate UK Technology Inspired Innovation – Self-Optimising Clean-in-Place
- *(subject to our consortium accepting the offer and submitting the required documents)*
- January 2016 – December 2016

Clean-in-place Monitoring

A. Simeone

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Introduction

CLEAN-IN-PLACE PROCESS

- Definition
  - Cleaning industrial equipment without disassembling.
- Main Issues
  - Use of hazardous chemicals
  - Use of water and energy
  - **Time**
- State-Of-The-Art
  - Manual inspection methodologies
- Objective
  - Real-time monitoring system

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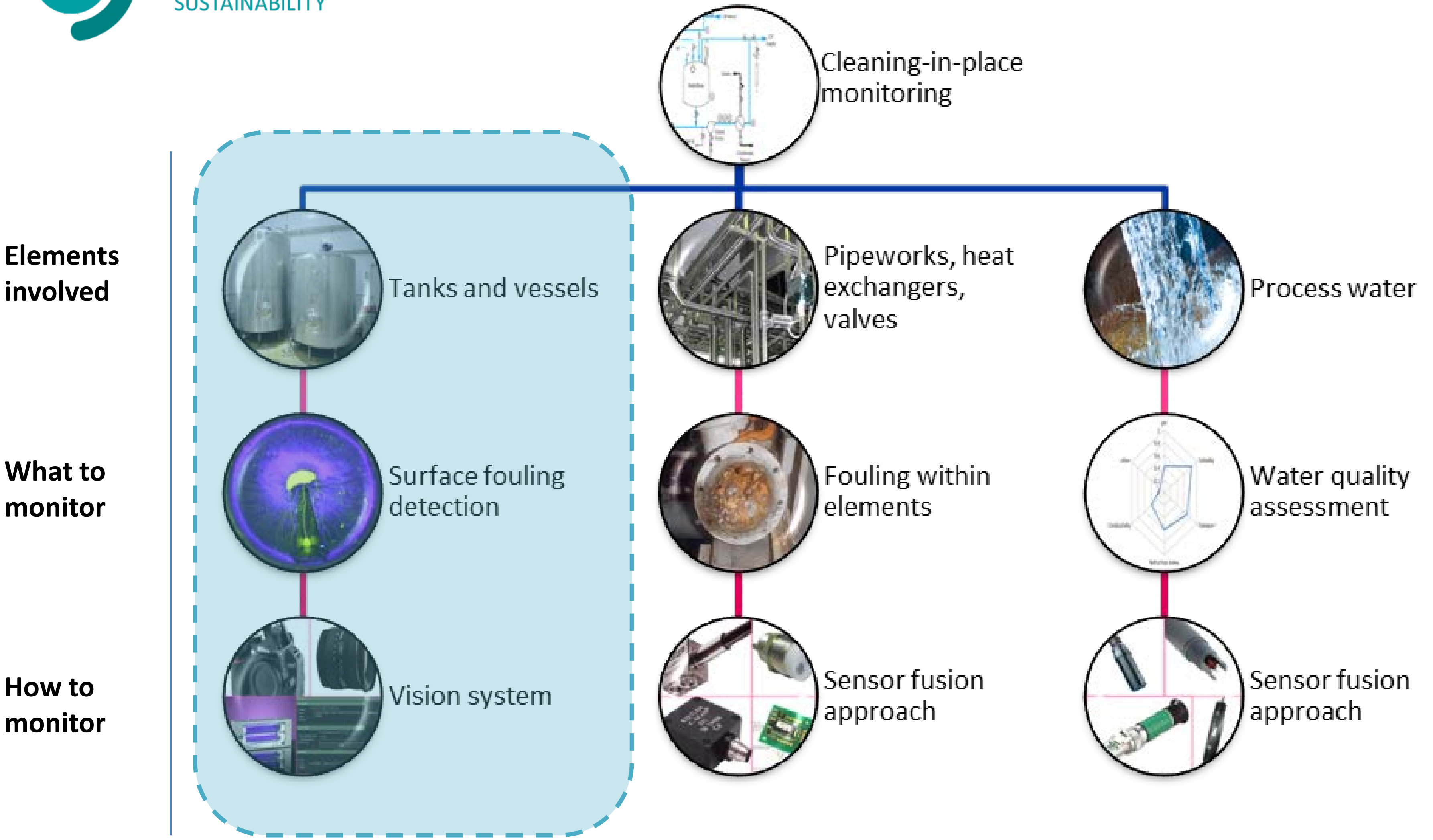
Research Framework



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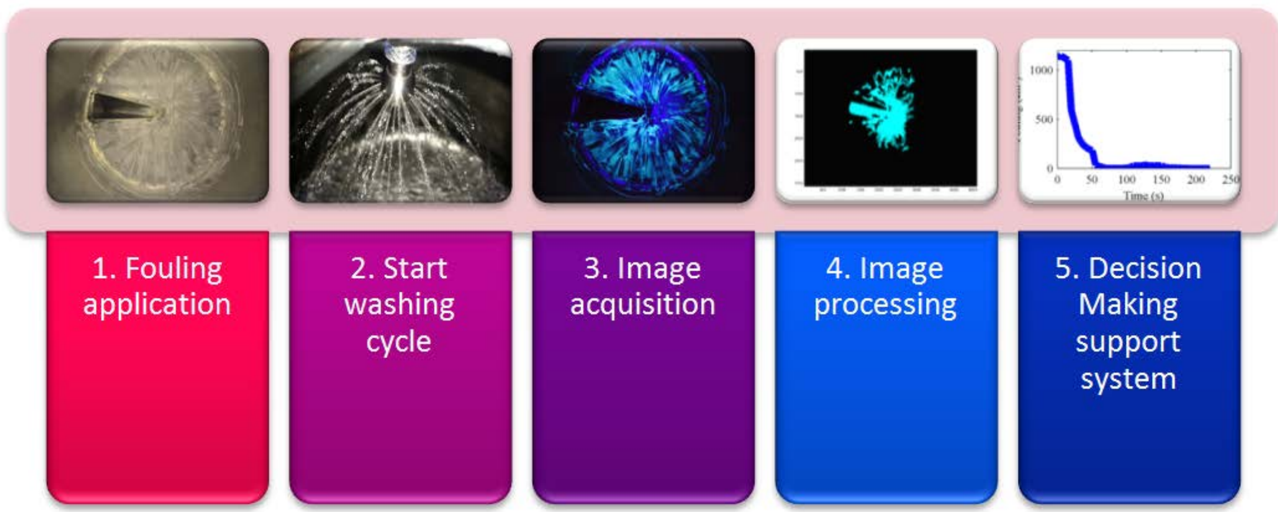
Research Methodology

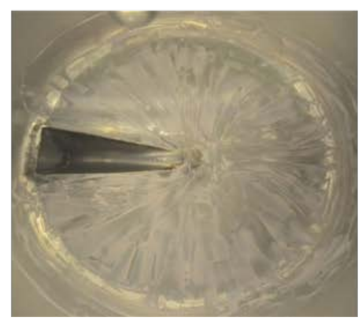


Research Methodology

1. FOULING APPLICATION

Riboflavin

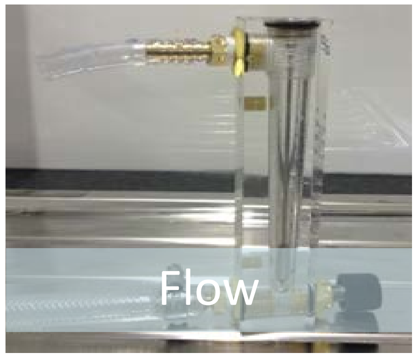
Yogurt

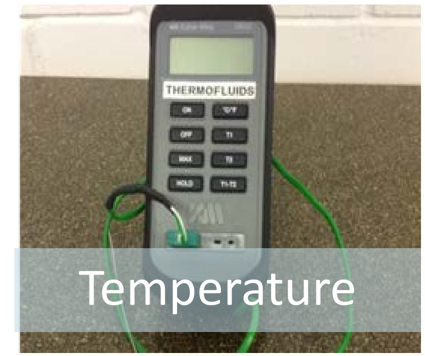


Ice Cream

Research Methodology

2. WASHING CYCLE





Research Methodology

IMAGE ACQUISITION

Camera

Nikon D3100

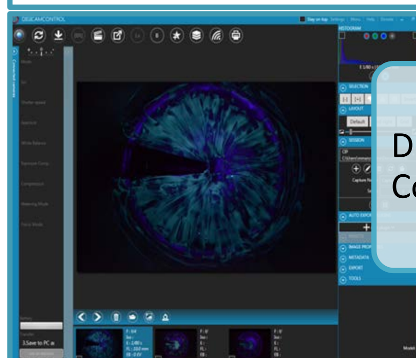
Zoom

Sigma 10-20mm

UV lights

UV 18W Blacklight Blue Tube Unit

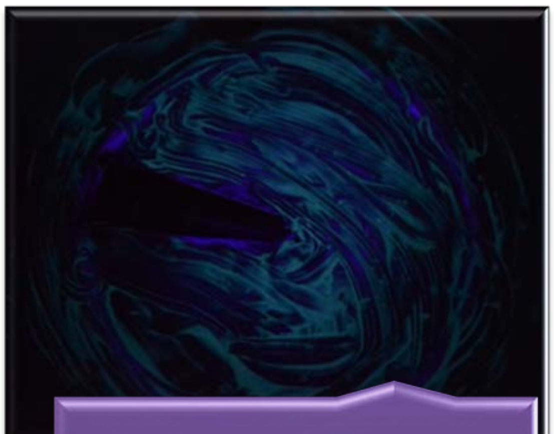
Time-lapse



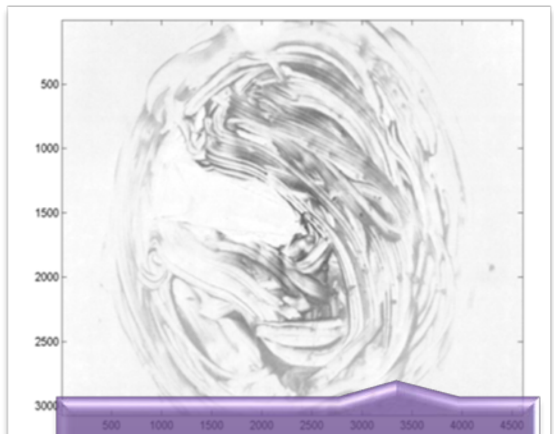
Digicam Control

Research Methodology

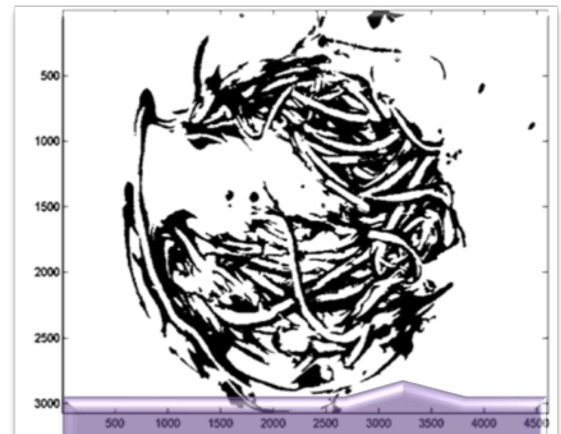
IMAGE PROCESSING



RGB



Green Channel



BW

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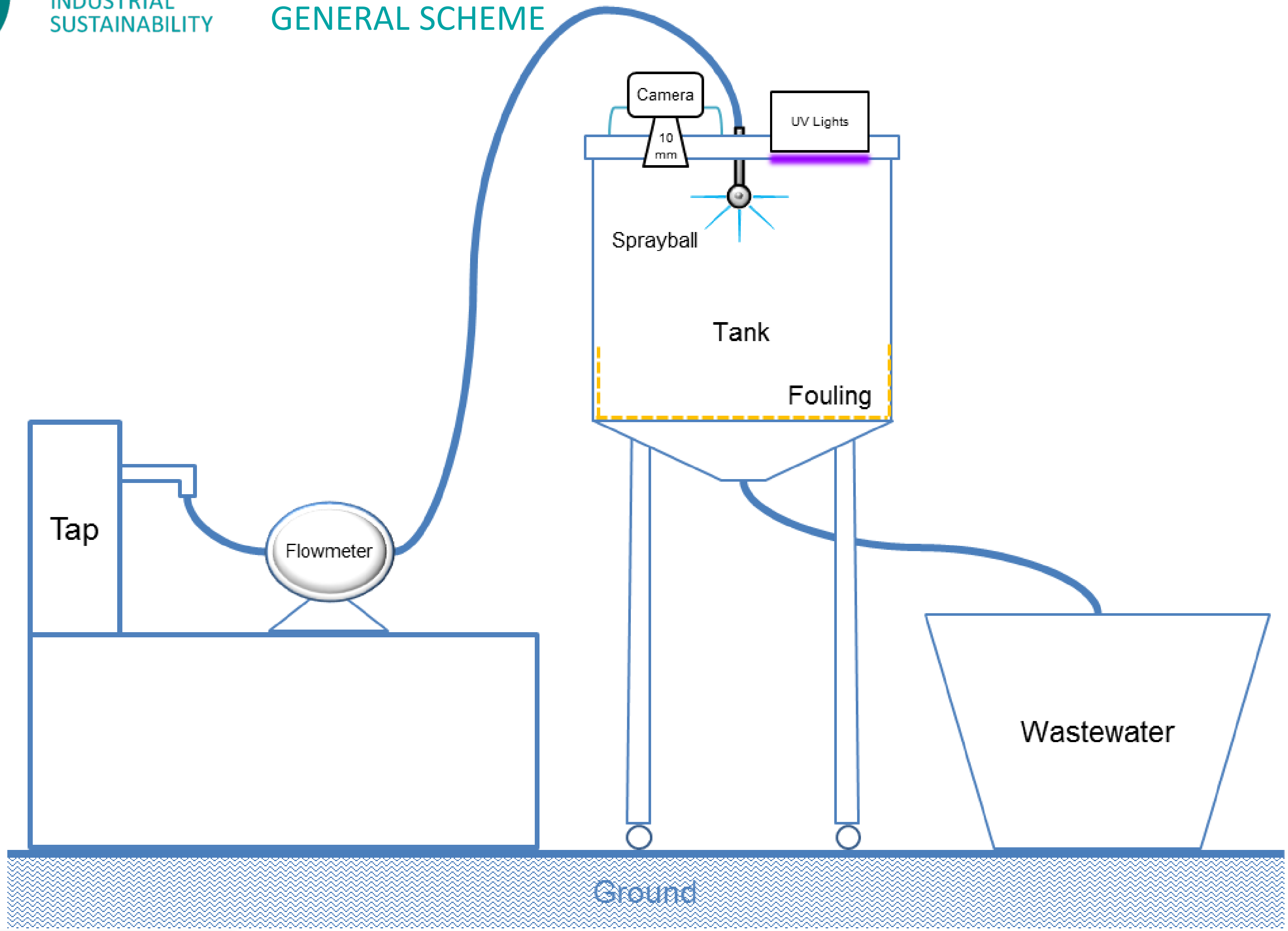
Experimental Setup

GENERAL SCHEME



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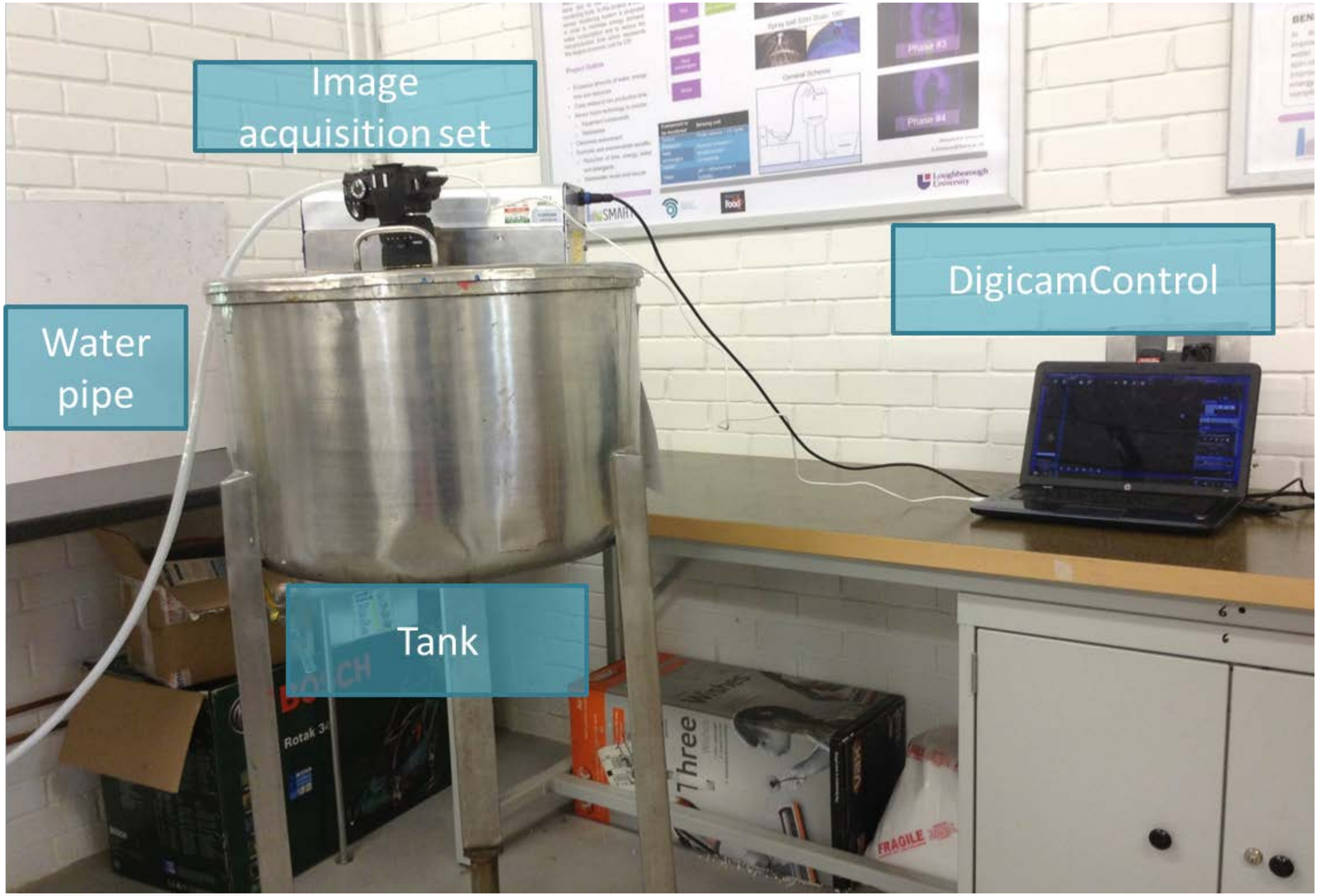
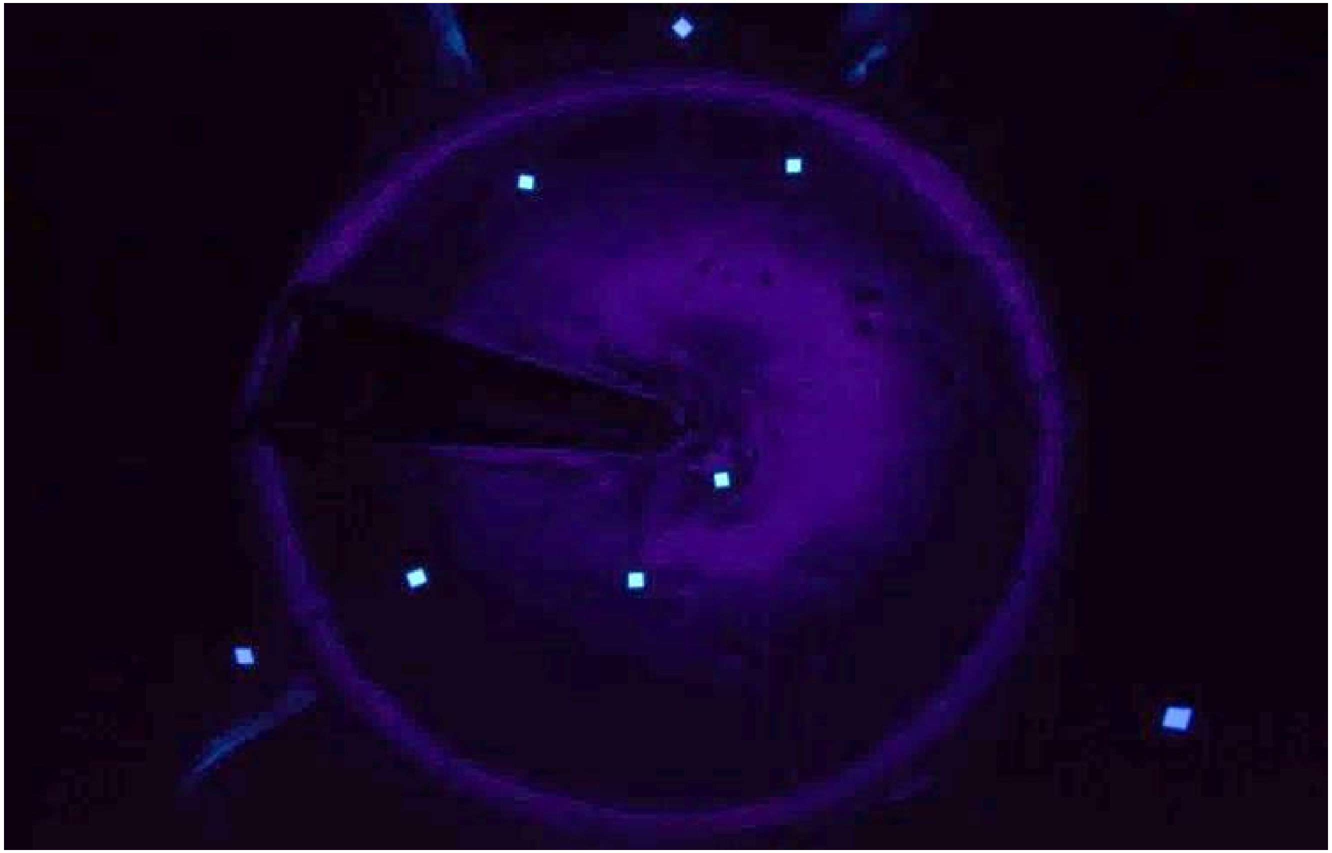
Experimental Setup

CONFIGURATION



Research Methodology

5. DECISION MAKING SUPPORT - TRANSFORMATION OF PIXELS IN MM^2



Bottom

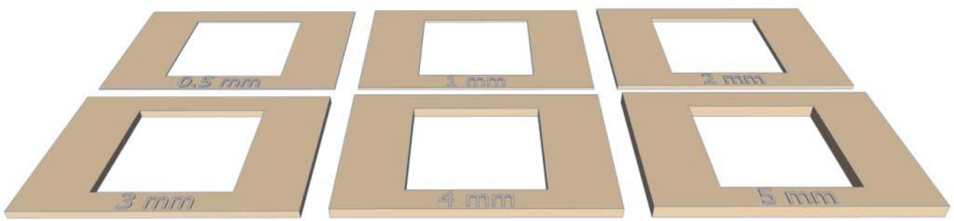
- *$1cm^2$ ~ 2000px*

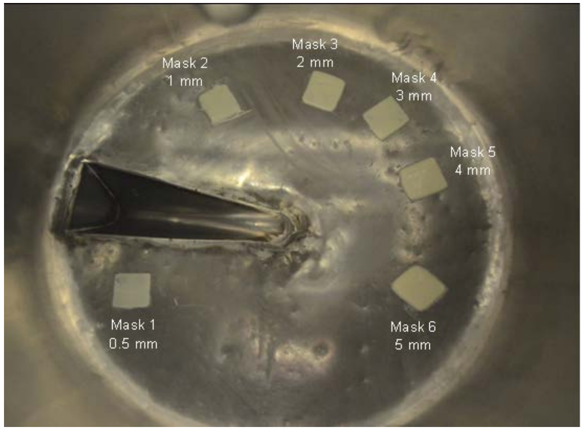
Side

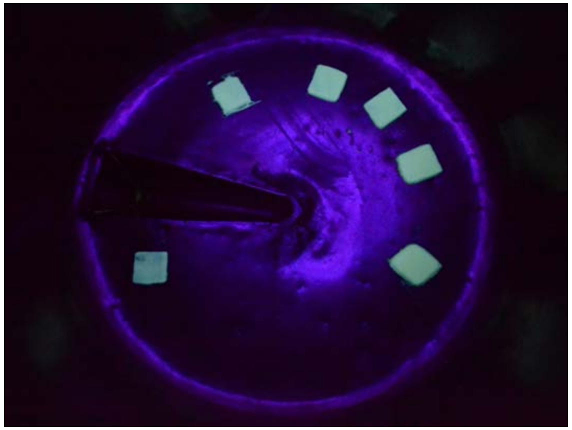
- *$1cm^2$ ~ 3000px*

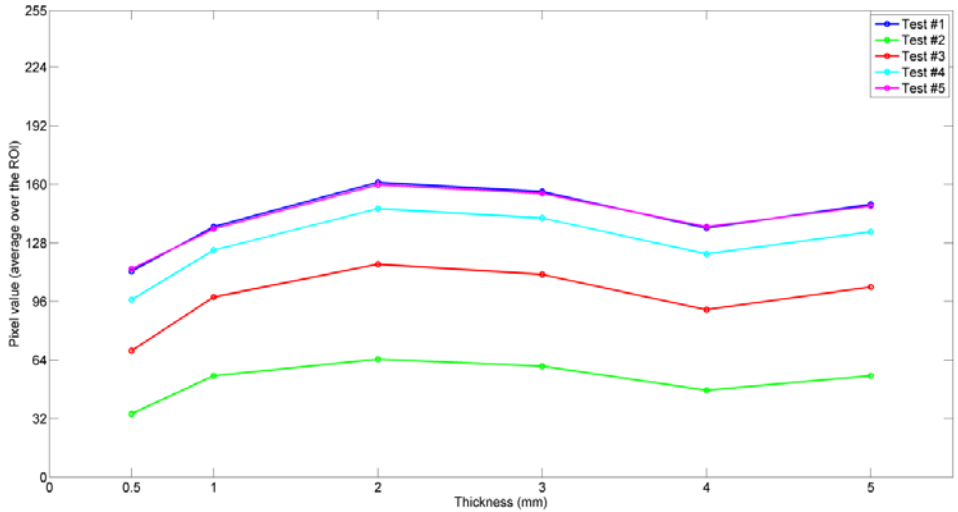
Decision Making

THICKNESS ANALYSIS



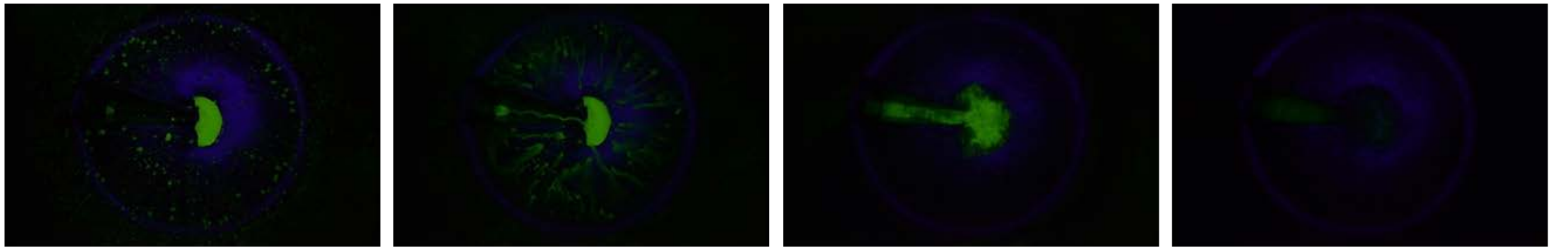




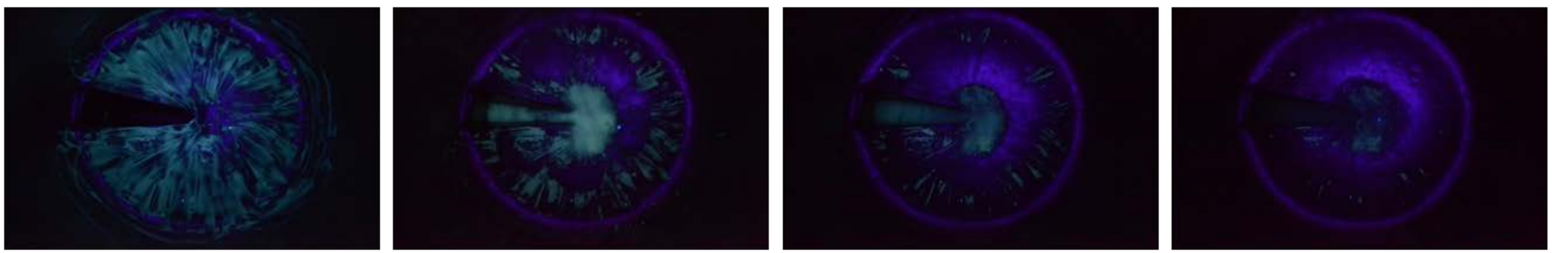


Results

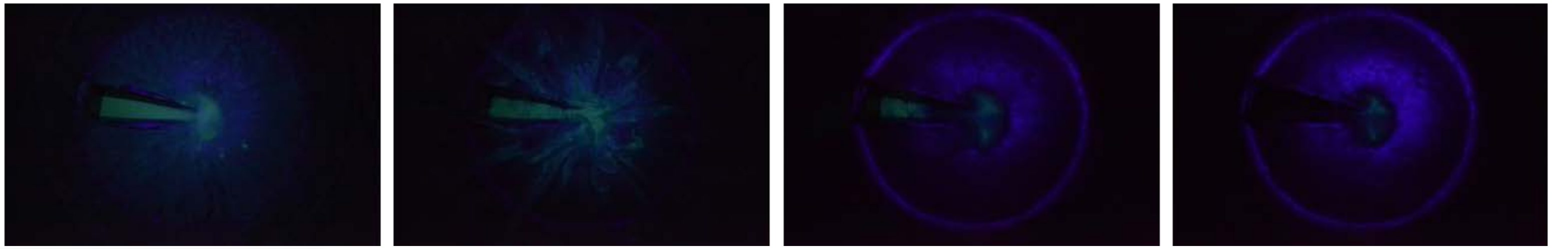
Riboflavin



Yogurt



Ice Cream



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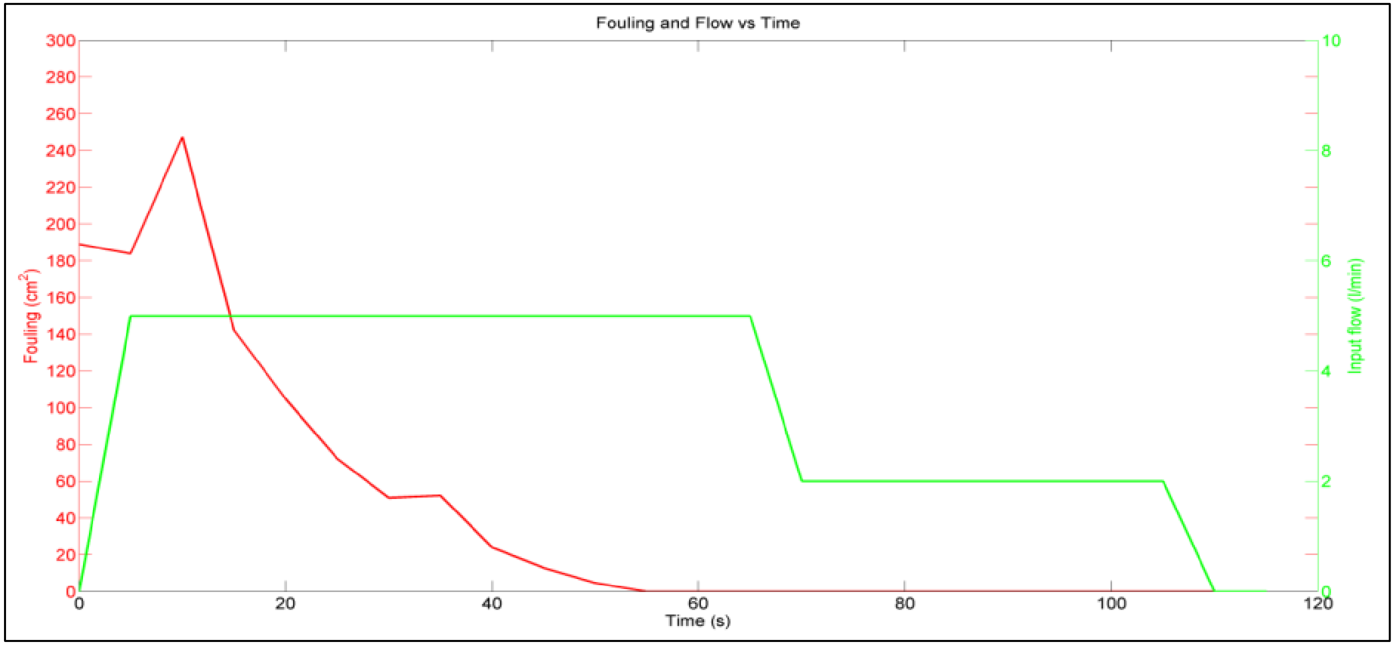
Results

ICE CREAM TESTS

Parameter		Value
Test ID		I2
Date		21 July 2015
Fouling agent		Ice cream
Fouling quantity		250 g
Water Temperature		20 °C
Detergent		None
Camera configuration	Exposure	1/100 sec.
	F-stop	f/4
	ISO	6400
	White balance	Manual
	Time Lapse	5 sec.



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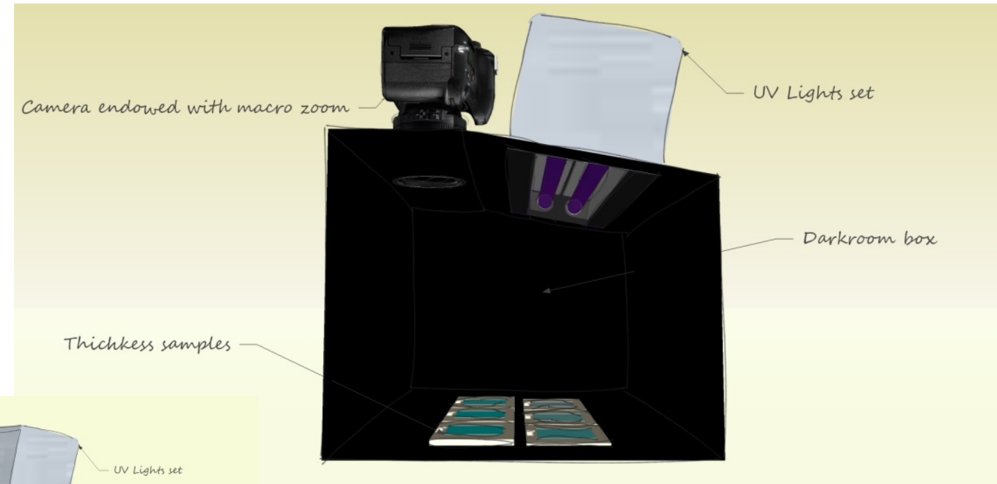
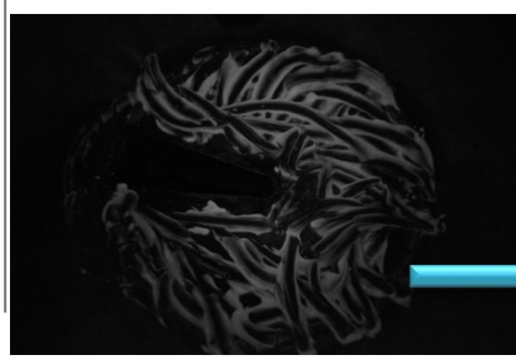
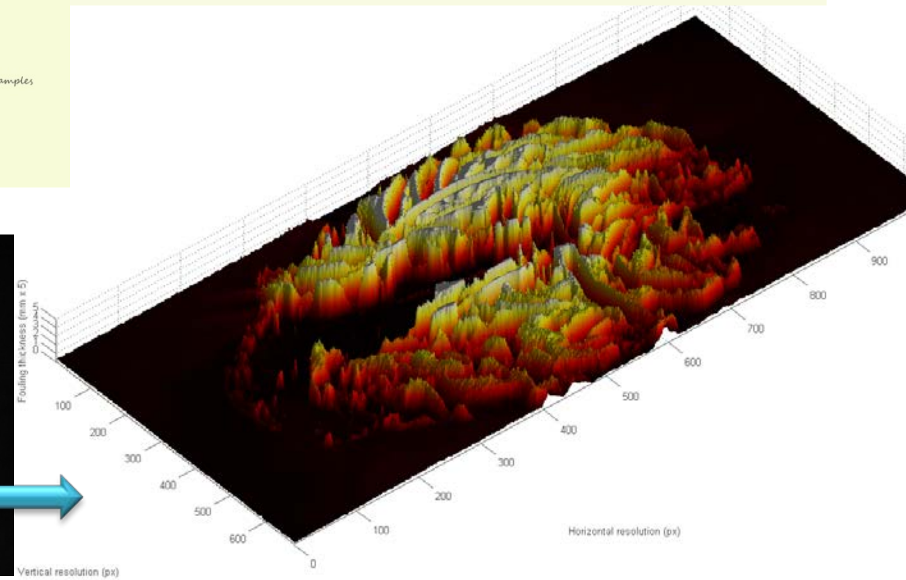
Conclusions

- Experimental campaign of 15 tests using 3 different fouling agents was carried out.
- Images were remote and automated acquired using a set of UV lights and a digital camera.
- Image processing was carried out extracting the Green Channel of every image and transforming it into a Black and White image.
- Fouling pixels in the Black and White images were transformed into surface units through the application of an experimental methodology.
- Fouling removal and water flow vs cleaning time were represented in plots for every test performed.

Future work







Thickness and intensity correlation

Thickness (mm) ≈ pixel intensity · θ

θ to be determined experimentally

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High Speed, Energy Efficient Manufacturing of Photovoltaics

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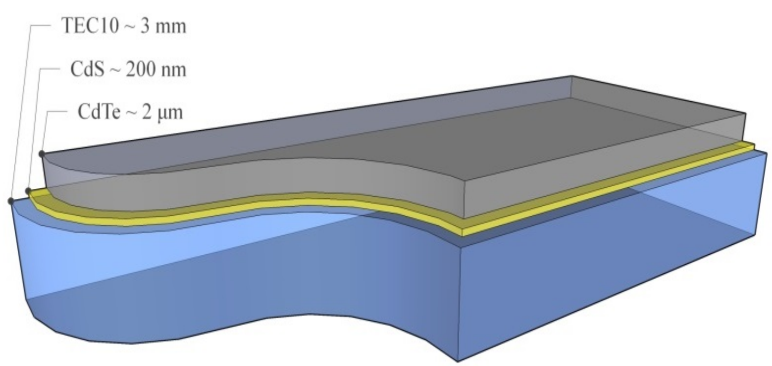
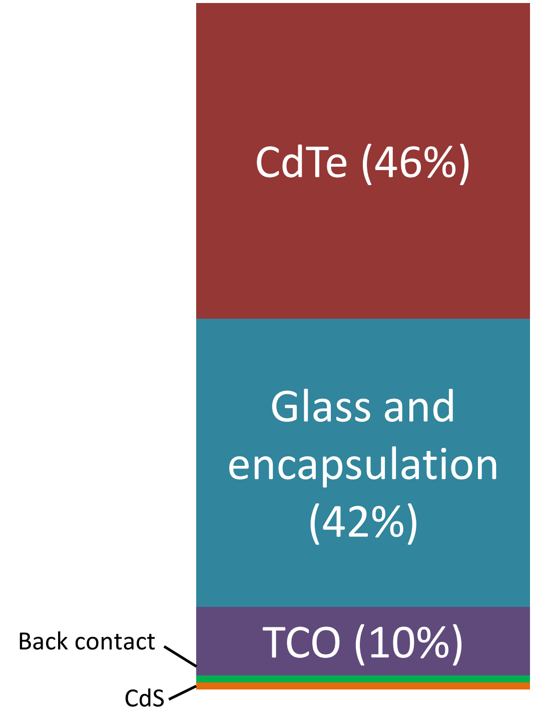
Embedded energy

- Embedded energy is the energy required to manufacture the PV module.
- Embedded energy from different types of PV module (Peng *et al*.) (mean values):
  - Mono-silicon PV ~ 3400 MJ/m^2
  - Multi-silicon PV ~ 3800 MJ/m^2
  - Thin-film PV technologies:
    - a-Si ~ **1200 MJ/m^2**
    - CIGS ~ **1070 MJ/m^2**
    - CdTe ~ **920 MJ/m^2**





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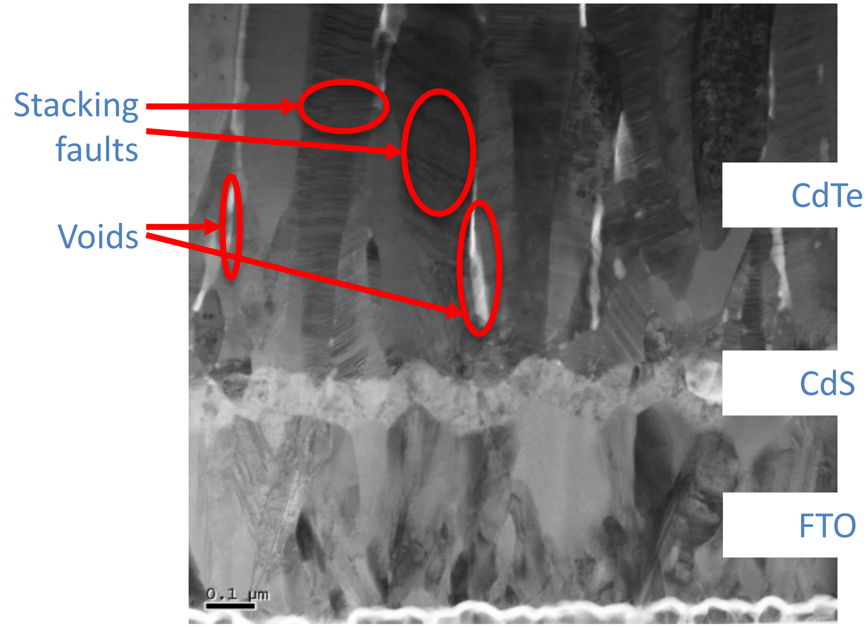
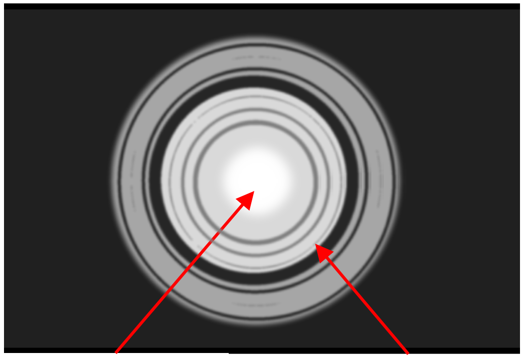
Optical inspection of CdTe panels

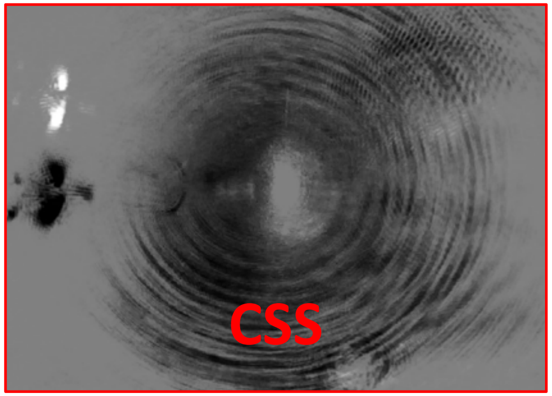
- Stacking faults and voids cause failures in panels.

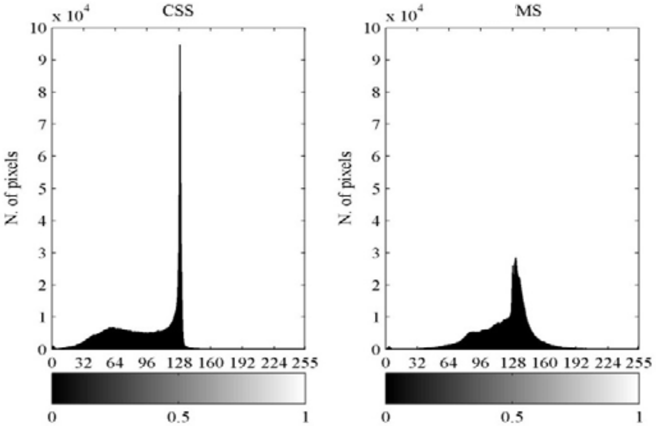


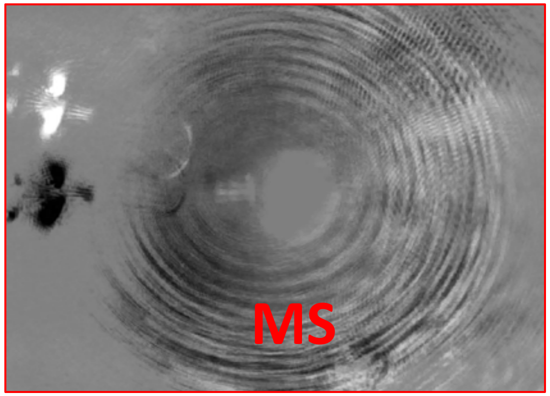
- Advantages of using an optical inspection system:
  - In-situ, non-invasive measurements
  - Can provide high-speed online real-time analysis
  - Allows panel quality to be inspected while in production

Optical Inspection of CdTe panels









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Using lasers for CdTe annealing

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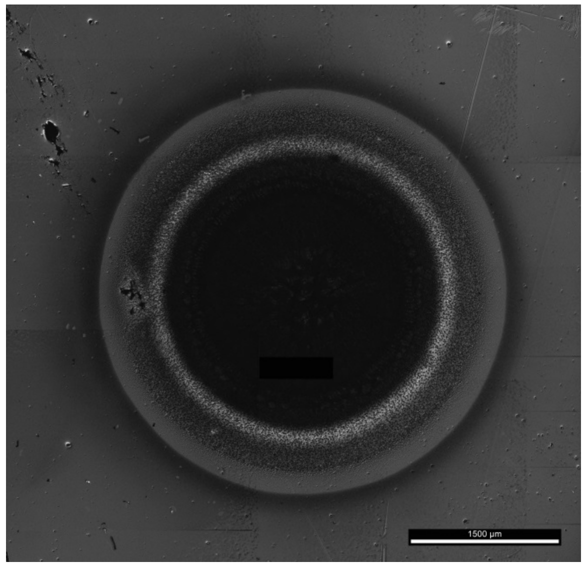
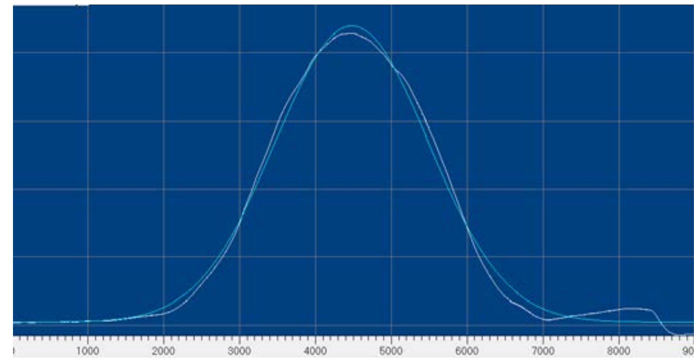
- Current annealing processes typically use a furnace to heat the entire panel for approximately 8 mins
  - Energy intensive
  - Inefficient
  - Slow

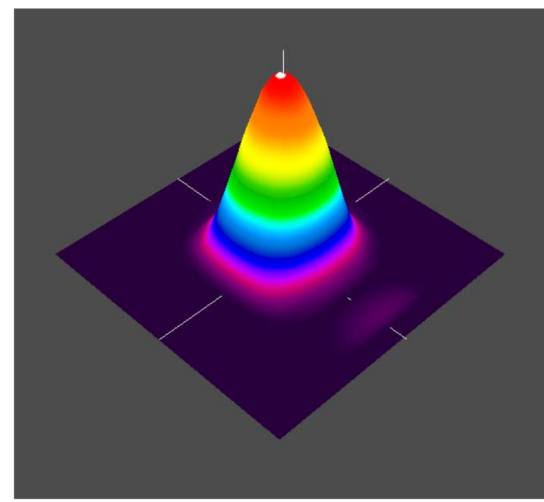
- The use of a laser offers improvements:
  - Energy reduction by only heating the top surface rather than the entire panel
  - Decrease in annealing time from 8 mins down to approximately 15 seconds
  - Energy resilience – the ability to halt process at any time with no repercussions
  - "Reel-to-reel" continuous production rather than batch production
  - Use of polymer or other non-glass substrate

Laser beam characterisation

- Laser beams take on a TEM_{00} energy distribution

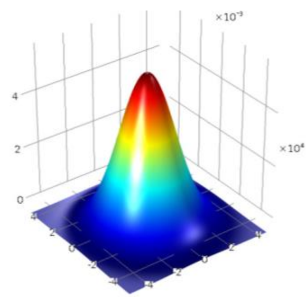






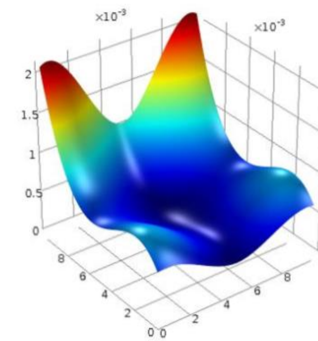
Using Holographic Optical Elements for thermal control

- Laser beam thermal control is achieved via use of Holographic Optical Elements (HOE's)



Gaussian beam

HOE



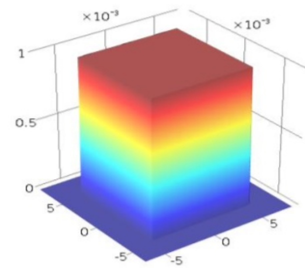
Optimised beam

- HOE's are manufactured either using e-beams or plasma etching, based on a computer-generated image

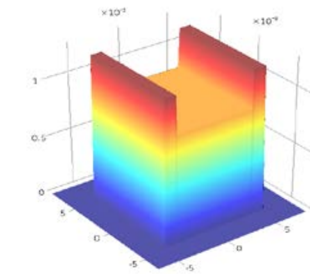
Laser beam optimisation

- The laser beam thermal distribution was optimised to give greater uniformity in temperature distribution.

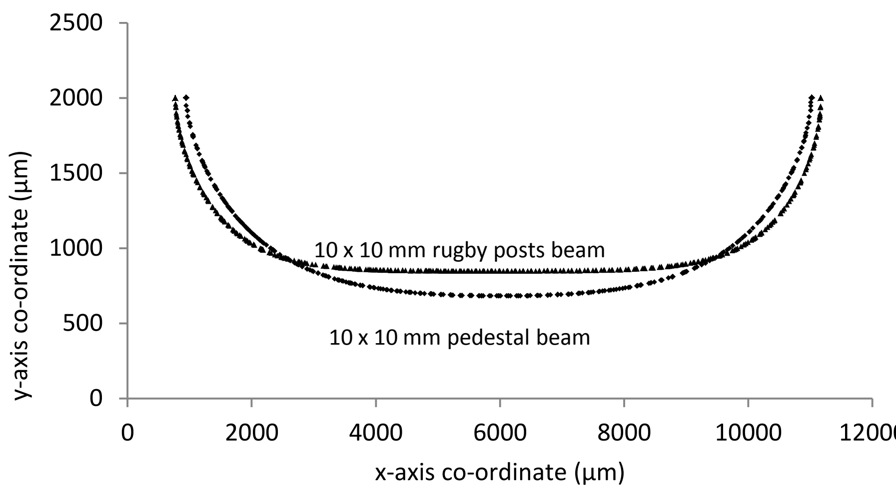
"Pedestal" beam

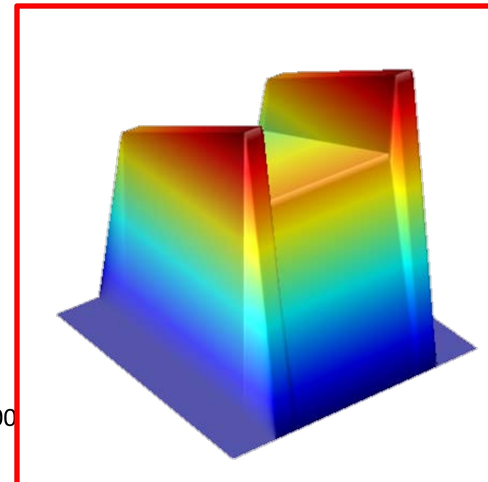


Beam traverse



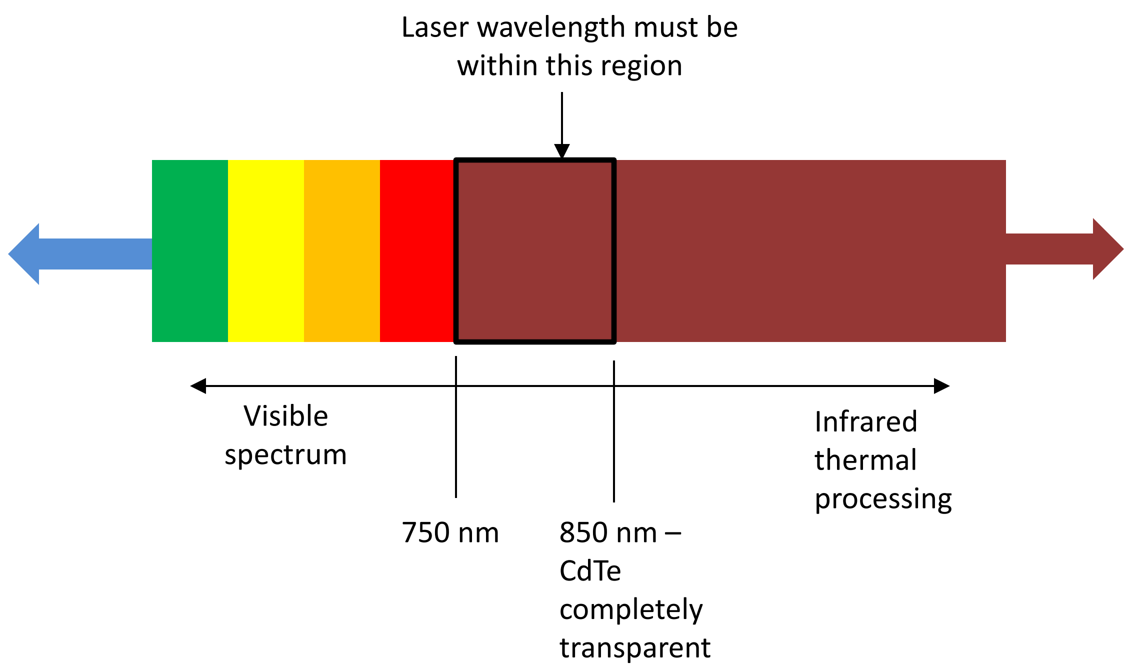
"Rugby posts" beam





Laser annealing equipment

- 808 nm wavelength selected as optimum
  - Long enough for infrared thermal processing
  - But not too long – CdTe is transparent to the majority of the infrared spectrum



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Laser annealing tests

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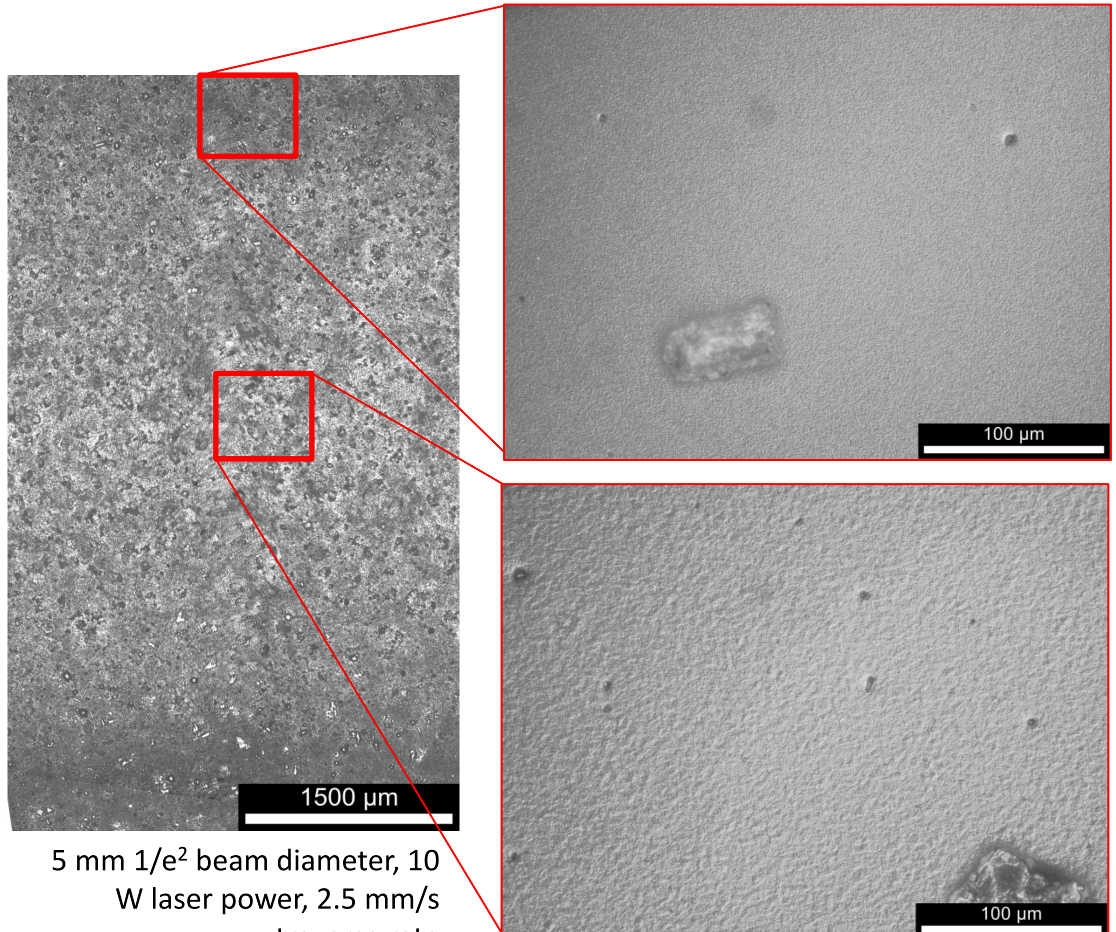

5 mm 1/e^2 beam diameter, 10 W laser power, 2.5 mm/s traverse rate

DIC optical micrograph of unprocessed surface

DIC optical micrograph of processed surface

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Conclusions

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- Solar photovoltaics are growing in importance worldwide, with CdTe thin film technology showing the most promise for development
- Optical inspection offers the ability to detect manufacturing faults non-invasively in real time
- Laser annealing offers advantages compared to traditional methods, principally:
    - Speed
    - Energy efficiency
    - Energy resilience
- Thermal effects of 808 nm laser beams have been observed experimentally. Experiments with holographic optics are due to commence

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Thank You

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