QDotFibreSense - Development of a rapid test system based on quantum dot functionalised filaments for explosive substances as a sensor glove for security forces

1st Digital Smart Material Summit | 16th May 2023
Introduction and Motivation

Security Checks

• Growing globalization lead to a steadily increasing number of travelers on airplanes

• Security checks at airports, stadiums or concert halls
  – Reduction of long queues
  – Quick and extensive implementation of security controls

• Current Methods for detection of hazardous substances:
  – Olfactory sensing by animals (e.g. sniffer dogs)
  – Swab tests in stationary spectrometry devices
    → time-consuming and cost-intensive
    → either long queues and/or inadequate checks at random
  – Other detection methods have been described, but not industrially implemented

“Itemiser 4DX“ for explosives by Rapiscan Systems
Introduction and Motivation

Security Checks

- Growing globalisation lead to a steadily increasing number of travellers on airplanes
- Security checks at airports, stadiums or concert halls
  - Reduction of long queues
  - Quick and extensive implementation of security controls
- Current Methods for detection of hazardous substances:
  - Olfactory sensing by animals (e.g. sniffer dogs)
  - Swab tests in stationary spectrometry devices
    → time-consuming and cost-intensive
    → either long queues and/or inadequate checks at random
  - Other detection methods have been described, but not industrially implemented
- Aim
  - Faster yet more comprehensive checks
  - Textile integrated low-investment sensor with swab tests
Introduction and Motivation

Concept of the sensor glove

• Textile glove with sensory areas at the tip of the fingers
• Custom-made electronics for power supply and control
• Exchangeable sensory ribbons
Introduction and Motivation

Polymer optical fibres

• Fiber Core:
  • Cylindrical and highly transparent polymer
  • Light conducting part of the fibre
    → Here: PMMA: Plexiglas 7N by Röhm GmbH, Darmstadt, Germany

• Fiber Cladding:
  • Creates constant light conduction by means of total reflection
  • Concentrically surrounded by a fibre cladding with a lower refractive index
    → Here: SiQD-doped PMMA by Applied Quantum Materials Inc., Edmonton, Alberta, Canada
Quantum Dots

- QDs nanosized semiconducting material
- Diameters in range of 2-10 nm
- e- confinement and discrete energy level
- Decrease in size increase band gap
Introduction and Motivation

Quantum Dots

- QDs nanosized semiconducting material
- Diameters in range of 2-10 nm
- e- confinement and discrete energy level
- Decrease in size increase band gap

Photoluminescence (PL) Mechanism

- QDs absorbs UV radiation to excite e-
- e- de-excite to recombine with the hole
- Energy (band gap) emits in the form of PL
Introduction and Motivation

Quantum Dots

- QDs nanosized semiconducting material
- Diameters in range of 2-10 nm
- e- confinement and discrete energy level
- Decrease in size increase band gap

Photoluminescence (PL) Mechanism

- QDs absorbs UV radiation to excite e-
- e- de-excite to recombine with the hole
- Energy (band gap) emits in the form of PL

Quenching/Detection Mechanism

- QDs absorbs UV radiation to excite e-
- +ve of acceptor attract the –ve of donor
- e- doesn’t de-excite back to hole
- Results in quenching of QD PL
Introduction and Motivation

Steps of development

- Project QDotFibreSense
- Development consists of five steps

- Applied Quantum Materials Inc., Edmonton, Canada (AQM):
  - Material specification/ SiQD production (Step 1)

- Institut für Textiltechnik of RWTH Aachen University (ITA):
  - Compounding (Step 2)
  - Fibre production (Step 3)

- ITP GmbH, Weimar, Germany (ITP):
  - Electronic development (Step 4)
  - Integration (Step 5)
Material specification/ SiQD production (Step 1)

Blending of QD with Polymer
Material specification/ SiQD production (Step 1)

Coating Process

Spray coating

Dip coating was the best method for even coating of sensors

Dip coating

Fabric

SiQD

Dip coated fabric

Uncoated fabric
Material specification/ SiQD production (Step 1)

Quenching Test

Quenching detected for 50 ng TNT

Fabric could be washed and reused for further detection of TNT

<table>
<thead>
<tr>
<th>(365 nm)</th>
<th>Before</th>
<th>After Quenching</th>
<th>After 24 hours</th>
<th>After Quenching (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative Control</td>
<td><img src="negative_control.png" alt="Image" /></td>
<td><img src="negative_control_quenched.png" alt="Image" /></td>
<td><img src="negative_control_after_24_hours.png" alt="Image" /></td>
<td><img src="negative_control_after_2nd_quench.png" alt="Image" /></td>
</tr>
<tr>
<td>Positive Control</td>
<td><img src="positive_control.png" alt="Image" /></td>
<td><img src="positive_control_quenched.png" alt="Image" /></td>
<td><img src="positive_control_after_24_hours.png" alt="Image" /></td>
<td><img src="positive_control_after_2nd_quench.png" alt="Image" /></td>
</tr>
<tr>
<td>Washing Study</td>
<td><img src="washing_study.png" alt="Image" /></td>
<td><img src="washing_study_quenched.png" alt="Image" /></td>
<td><img src="washing_study_after_24_hours.png" alt="Image" /></td>
<td><img src="washing_study_after_2nd_quench.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Compounding (Step 2)

➔ Dilute the SiQD compound to desired concentration

- Weighing and mixing the SiQDs with the corresponding polymer
- Drying the SiQD-polymer-mixture in a vacuum drying oven to the desired moisture content
- Compound the
- Granulation of the cooled extrudate to 5 mm long polymer granules

Polymer with 14% SiQDs

Polymer with 1% SiQDs each

Micro compounding
Fibre production (Step 3)

→ Production of a circular functionalised POF with a total fibre diameter of 300 µm with a cladding thickness of 10 µm

- Bicomponent monofilament meltspinning
- Melting the pure polymer in the core extruder
- Melting the SiQD-polymer-compound in the cladding extruder simultaneously
- Cooling the bicomponent fibre in a water bath
- Finally winding the POF on a bobbin

Schematic illustration of the bicomponent spinning process
Fibre production (Step 3)

Investigations at the polymer level

- TGA analyses:
  - concentration of 1 % SiQDs, no significant effect
- DSC investigations:
  - glass transition temperature, slightly reduced.

Investigations at the fiber level

- Tenacity of SiQD-POF, reduced by around 22 %
- Attenuation, heavily increased (factor >7)
Fibre production (Step 3)

Fluorescence Measurements

a) Fiber level measurement

b) Fabric level measurement

POF with QD
POF without QD
**Fibre production (Step 3)**

**Quenching Trials**

- Wipe test of the fibre with following mixture:
  - TNT
  - Acetonitrile
  - Methanol
- Coated aluminium strips are used as a backing.

*Applying the TNT solution*  *Soaking the sample*
Electronic development (Step 4)

Sensor Ribbons

- Polyester weaving with five integrated PMMA fibres
- Coated with Quantum Dots
- Combined with LED in an adapter piece
- Exchangeable, can be saved as evidence or further analysis
- Fixation points on adapter and end part of the ribbon
Electronic development (Step 4)

Electronics

- 2-way-safety: ON/OFF-Switch and separate POWER switch for LEDs
- LED is timed: 20 s until automatically switching off
- Chargeable via micro-USB, capacity of 0.9 Wh
- Charge indicator with four LEDs, can be activated via a separate button
Integration (Step 5)

Prototype

- Fingerstall with hook-and-loop-fastener for fixation of further components
- Electronics for control and power supply (ca. 1 working shift)
- Excitation wavelength: UV-A (390 nm)
- QD-coated sensory ribbons, exchangeable
Summary and Outlook

Summary

- **AQM:**
  - SiQD production
  - Quenching Test
  - Blending SiQDs into Polymers

- **ITA:**
  - Compounding
  - Fibre production an Testing

- **ITP:**
  - Smart glove design
  - Design of the electronic components

Outlook

- Further development to a market maturity sensor system
- Field test via established contacts to:
  - State Office of Criminal Investigation Thuringia (LKA Thüringen)
  - Royal Canadian Mountain Police
**ACKNOWLEDGMENT**

The project on which this report is based was funded by the Federal Ministry for Economic Affairs and Climate Action under the funding number ZF4558958AW9 and ZF4111306AW9. The authors are responsible for the content of this publication.

**Textile Innovations**

**Sustainable.Digital.Individual.**

---

**Project Consortium**

<table>
<thead>
<tr>
<th>David Antoniuk</th>
<th>Jan Kallweit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ania Sergeenko</td>
<td>Mark Pätzel</td>
</tr>
<tr>
<td>Larissa Smith</td>
<td></td>
</tr>
<tr>
<td>Caoimhe Connaughton</td>
<td></td>
</tr>
<tr>
<td>Nduka Ikpo</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Klaus Richter</td>
</tr>
<tr>
<td></td>
<td>Luise Böhme</td>
</tr>
<tr>
<td></td>
<td>Wolfram Hartramph</td>
</tr>
</tbody>
</table>

---

**Sponsored by the Federal Ministry of Education and Research**

---

**Thank you for your attention!**