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Additive Manufacturing Low-Dimensional Optoelectronic Devices

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1. Introduction

High performance optoelectronic devices have been achieved by combining the optical properties of 0-dimensional (0D) materials such as perovskite nanocrystals (PNCs) with the electrical properties of 2-dimensional (2D) materials such as graphene [1-3]. However, upscaling the processing and manufacturing of these devices is challenging. The overall aim of this project is to develop and improve our understanding of low-dimensional (low-D) function materials deposited by additive manufacturing (AM) towards the goal of upscaling the manufacturing of high performance optoelectronic devices.

2. Inkjet printing low-dimensional materials

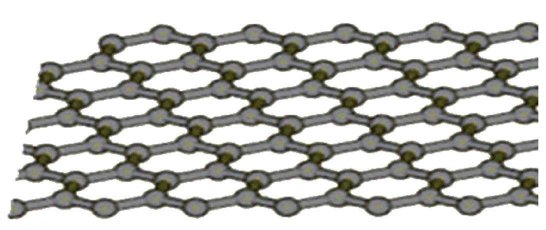
We deposit materials by inkjet printing: an additive manufacturing technique where droplets are ejected through a nozzle onto a substrate in a pre-set pattern.

Inkjet printing is a cheap and low-waste method for deposition of low-D materials over large areas so has potential to bring low-D optoelectronic devices to a commercial scale.

3. Formulating low-dimensional materials for AM

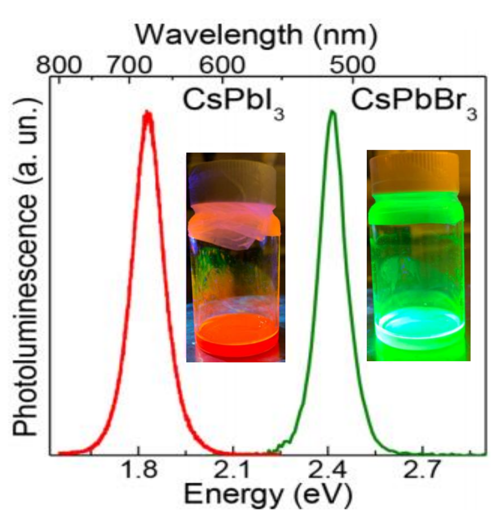
For each material we print, an ink must be formulated with the optimal viscosity, surface tension, and density for favourable jetting and drying, which can be challenging. Here we use 2 materials:

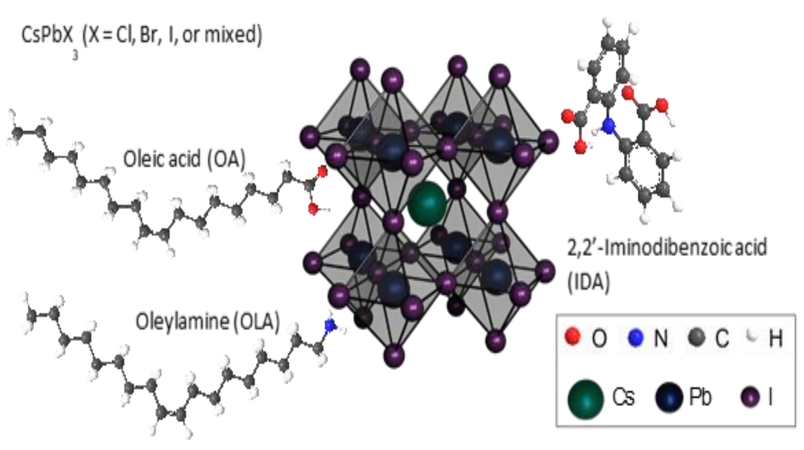
Graphene:
- 2D material with high conductivity and flexibility
- Used as a charge transfer material in optoelectronic devices
- We use a commercial graphene ink which contains ethyl cellulose which improves conductivity after annealing [4]



Perovskite Nanocrystals (PNCs):
- Highly fluorescent 0D material with ~90% quantum yield [5]

Tuneable bandgap by NC size and composition
- Used as the optically active material in optoelectronic devices [2,3,5]
- Not previously formulated for inkjet printing





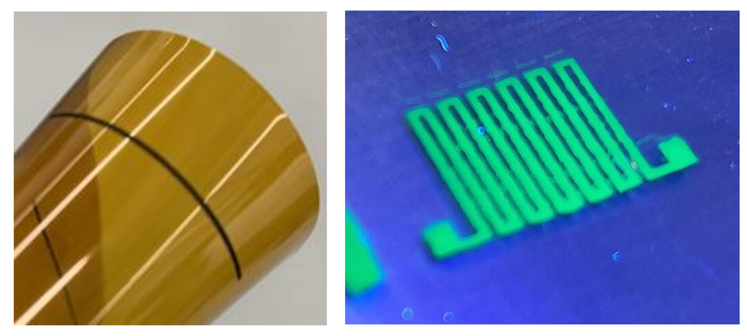
We formulated 2 new inks for inkjet printing:
1. Inks containing just PNCs
2. A PNCs/Graphene composite ink

4. Printed perovskite/graphene photodetectors

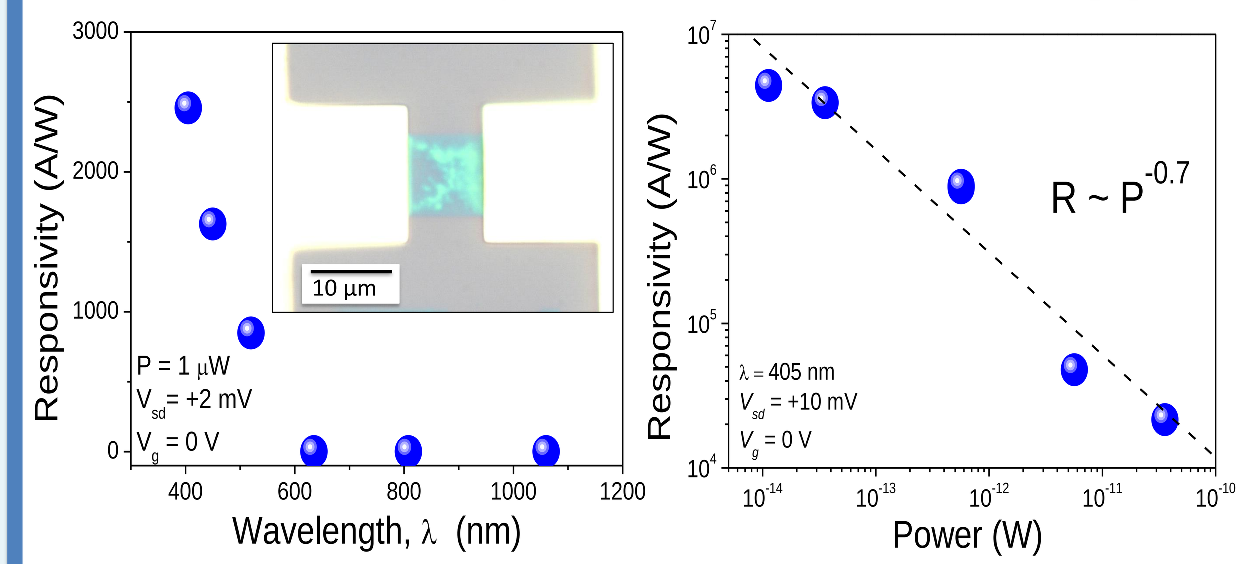
Printed patterns on various substrates including flexible substrates:

Printed green $CsPbBr_3$ and red $CsPbI_3$ PNCs on Si (under UV):

Printed green $CsPbBr_3$/graphene composite on Kapton and glass:

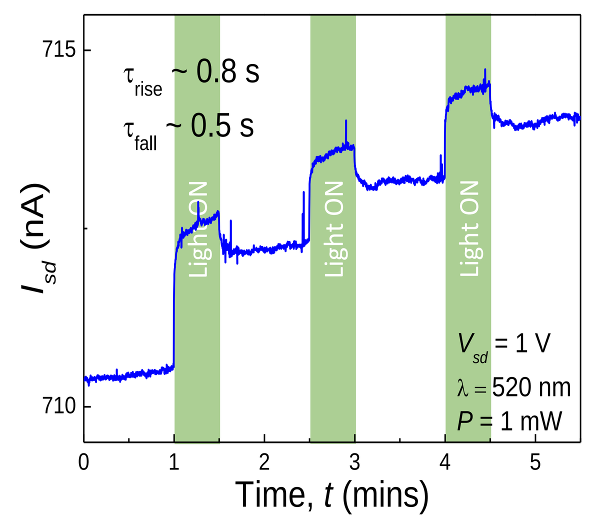


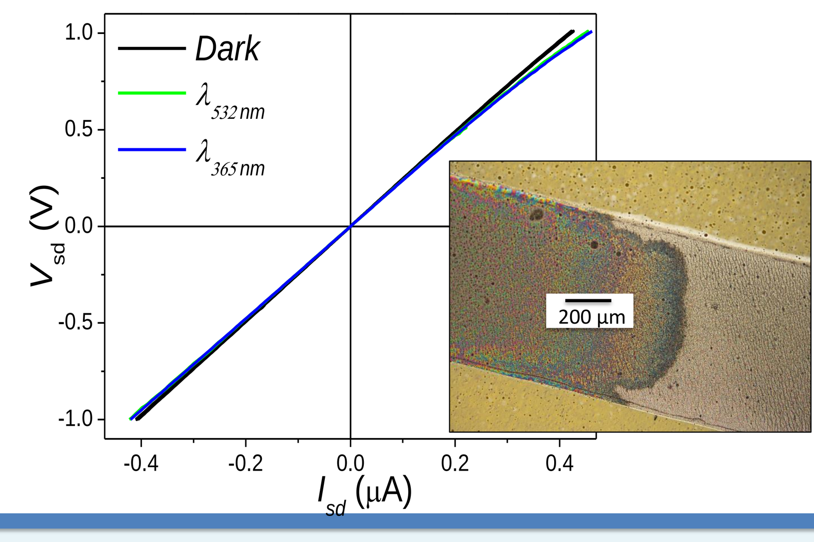
Printed Perovskite Photodetectors:
We fabricated photodetectors by printing the PNCs onto CVD graphene which achieved a maximum responsivity of **R = 10⁶ A/W**, 3 orders of magnitude better than the best printed device in literature [1].



The next step is fabricating fully-printed graphene/PNC photodetectors. We have explored two methods to achieve this:

1. **PNC/Graphene composite ink**
By combining the optically active and charge transport materials into a single ink, we printed graphene/PNC photodetectors in a single step. With fast response times and a responsivity of **R = 10⁻³ A/W.**



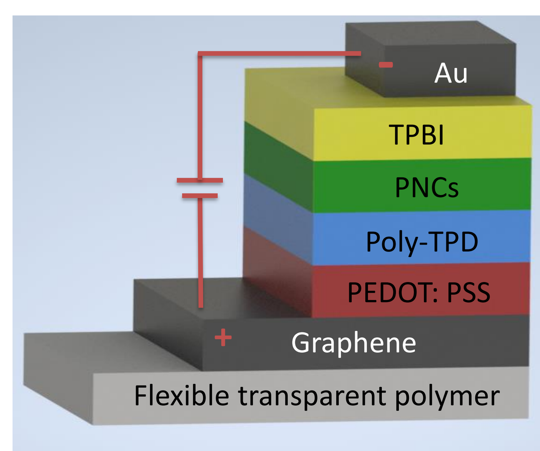


2. **PNC/Graphene heterostructures**
We also printed PNCs on top of inkjet printed graphene, giving a photoreponse of **R = 10⁻¹ A/W.**

5. Future work

Building on this work with printed PNCs and graphene, we aim to make the first fully-printed LED with 6 printed layers.

So far we have developed printing for each of the 6 materials. Next we will assemble the device and characterise the complex interfaces between each material to ensure functionality.



References:
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