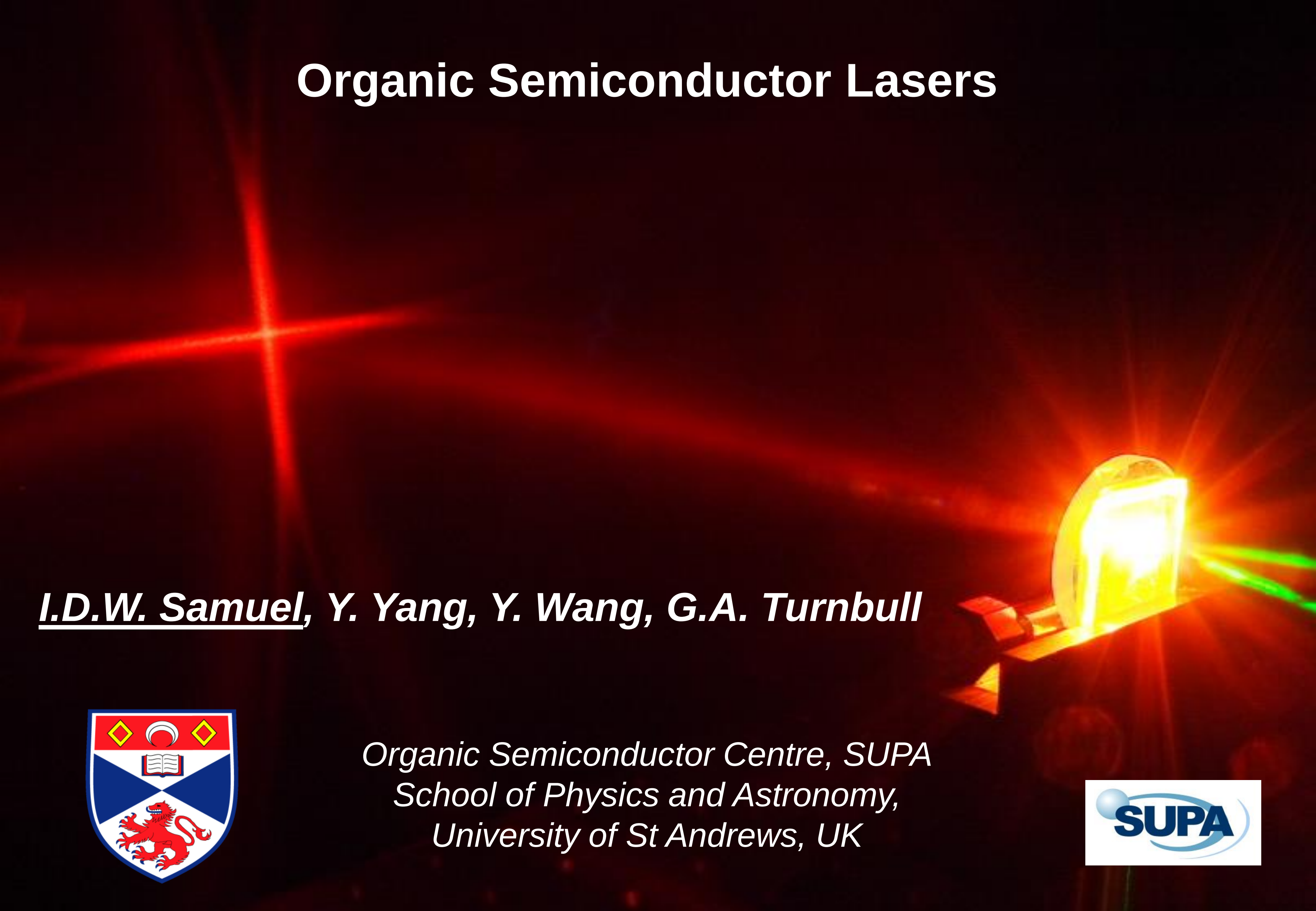


Organic Semiconductor Lasers

***I.D.W. Samuel*, Y. Yang, Y. Wang, G.A. Turnbull**

Organic Semiconductor Centre, SUPA
School of Physics and Astronomy,
University of St Andrews, UK

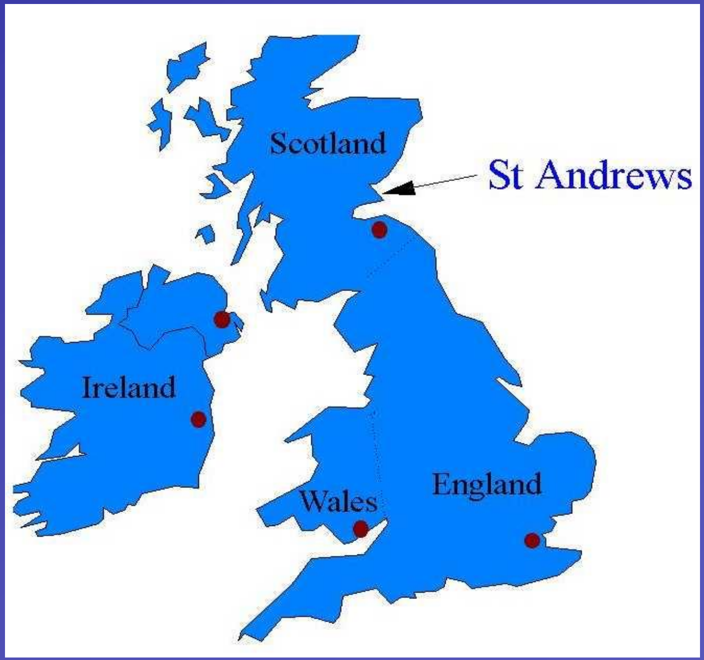
Outline

Introduction
- Polymer lasers and photonics
- Very brief history

Distributed feedback lasers

Nitride LED pumped polymer laser

Explosive sensing



Organic Semiconductors

Conjugated molecules

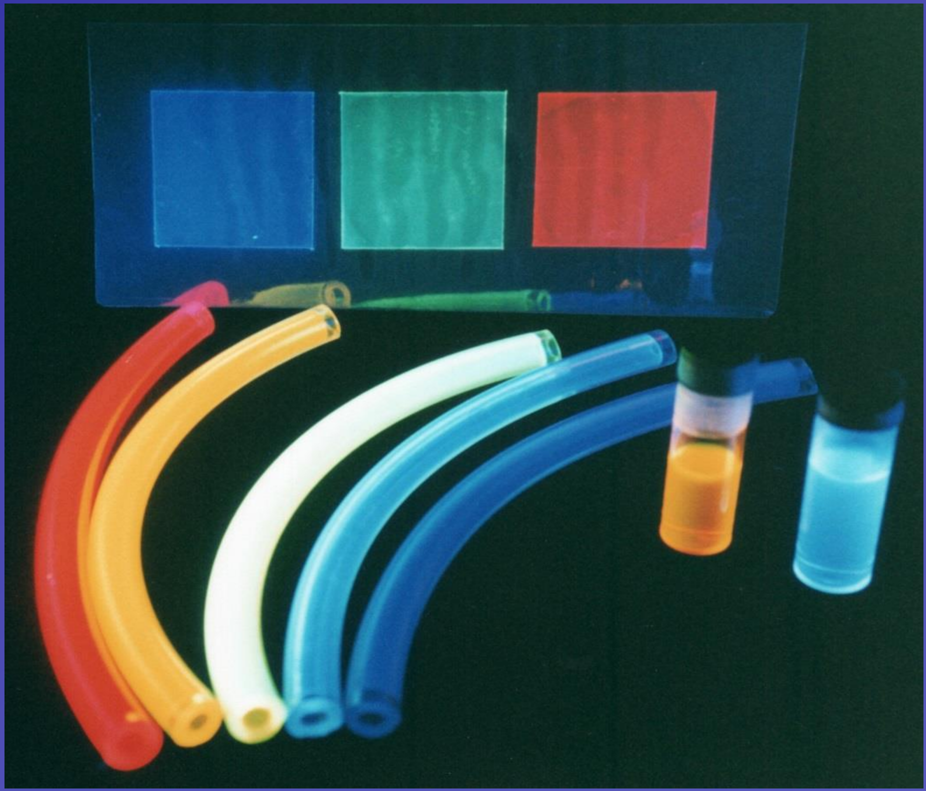
Novel semiconductors

Easy to process

Can tune properties

Can emit light

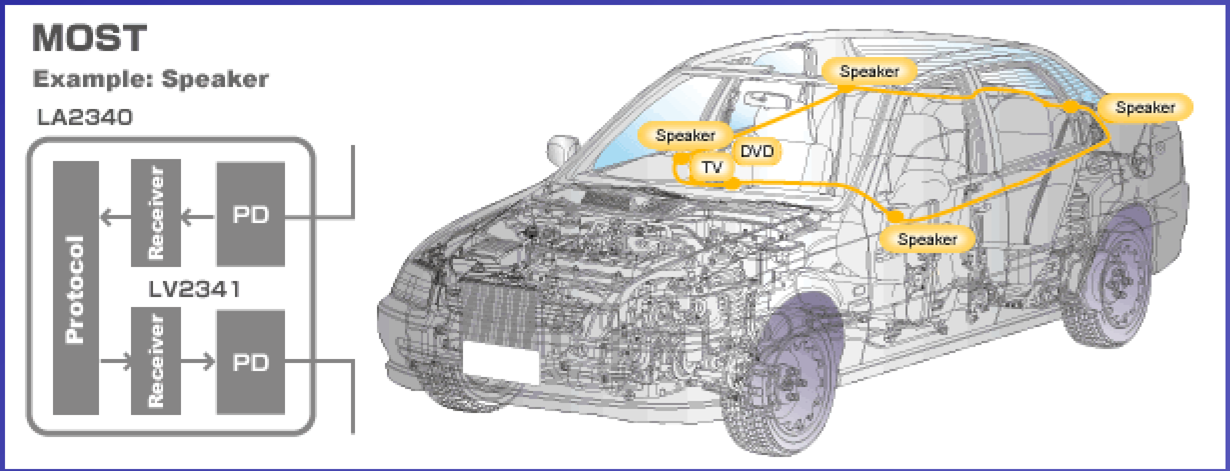
Flexible



Plastic Photonics

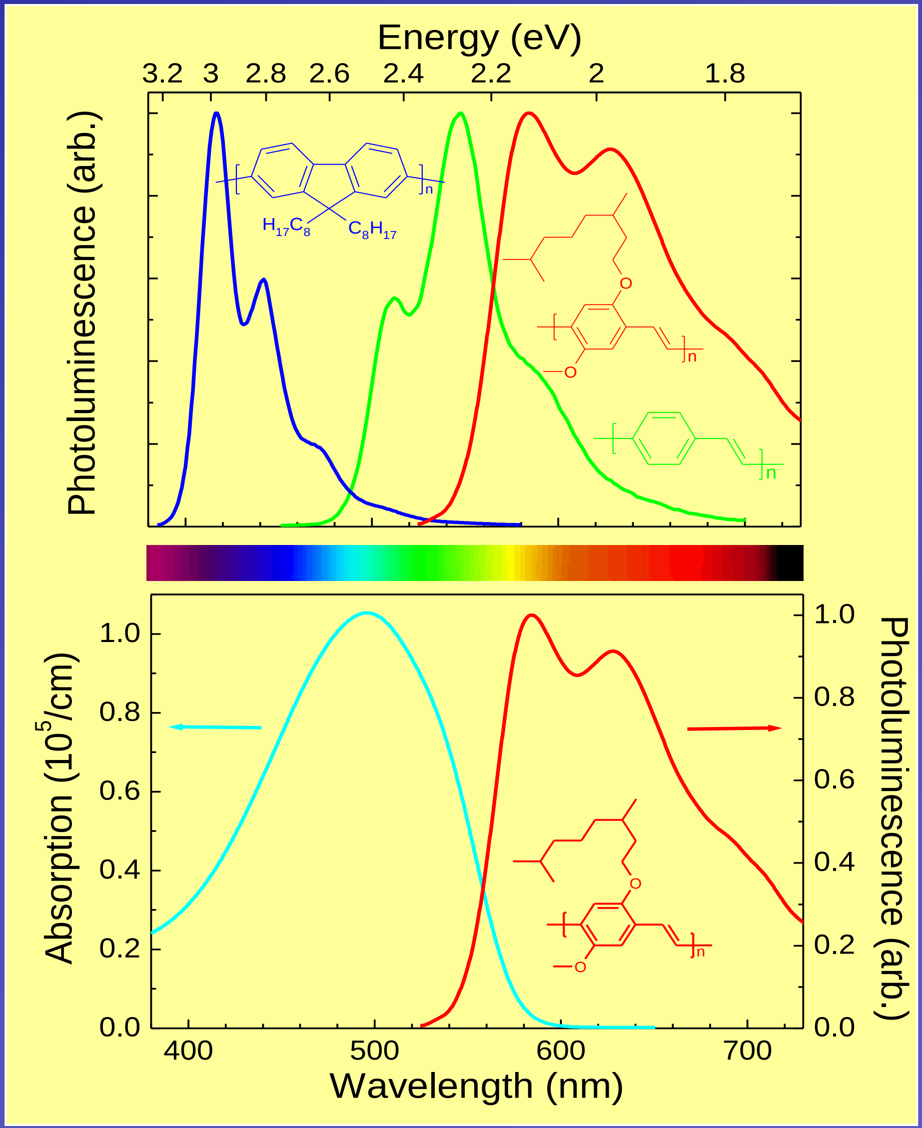
Passive

Active



Potential for Polymer Lasers +Amplifiers

- Absorption and emission separated - 4 level system
- Strong absorption ~10^5 cm^{-1} - Enormous gain
- Little concentration quenching
- Broad spectra - broad bandwidth
- Compatible with polymer fibre transmission windows (500–560 and ~660 nm),
- Scope for low cost manufacture
- Possibility of electrical pumping

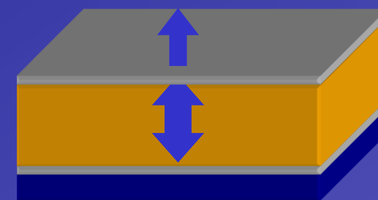


Early Semiconducting Polymer Lasers

Mirrors, MEH-PPV solution

Moses 1992

Q-switched Nd:YAG laser pump



Microcavity, PPV film

Tessler, Denton, Friend 1996

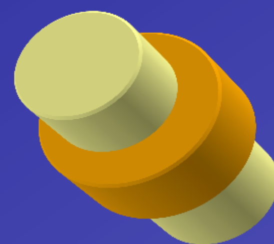
Regenerative amplifier pump

Polymer laser resonator geometries

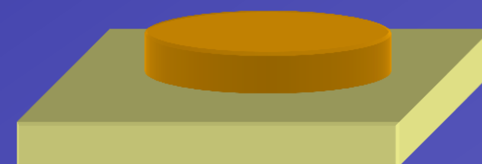
Solution processing- high quality waveguides

Sub-micron structures- laser microresonators

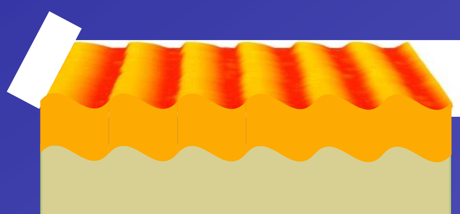
microcavity



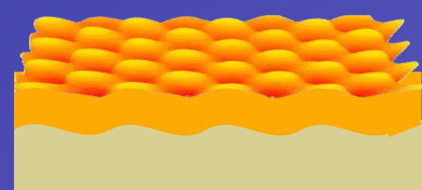
microring



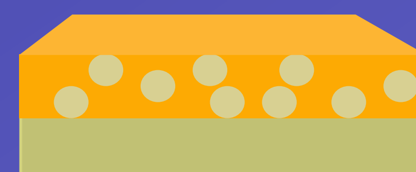
microring



1-D DFB



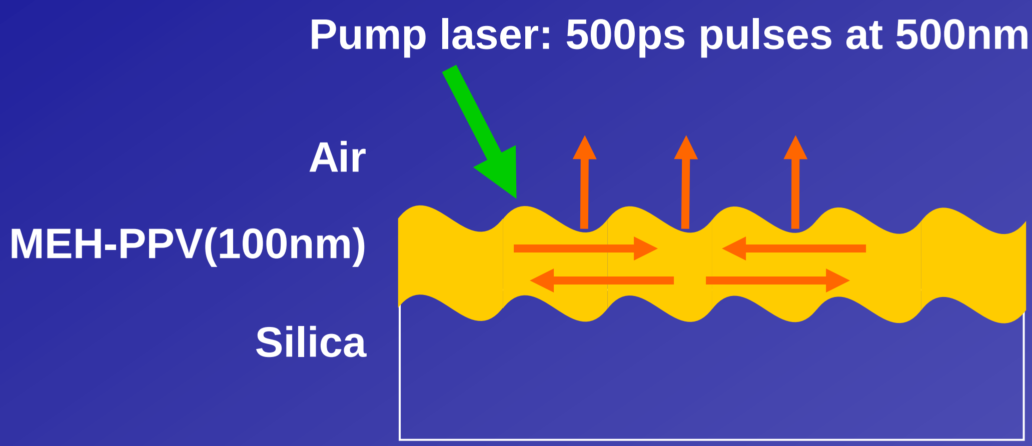
2-D DFB /
photonic crystal



random scatterers

Chemical Reviews **107** 1272 (2007)

Distributed Feedback Lasing

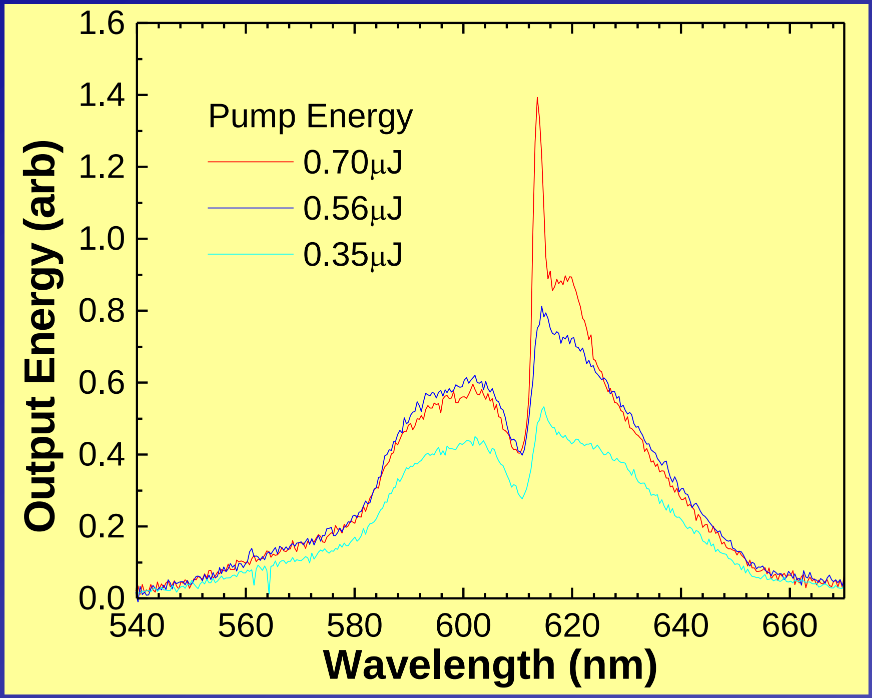


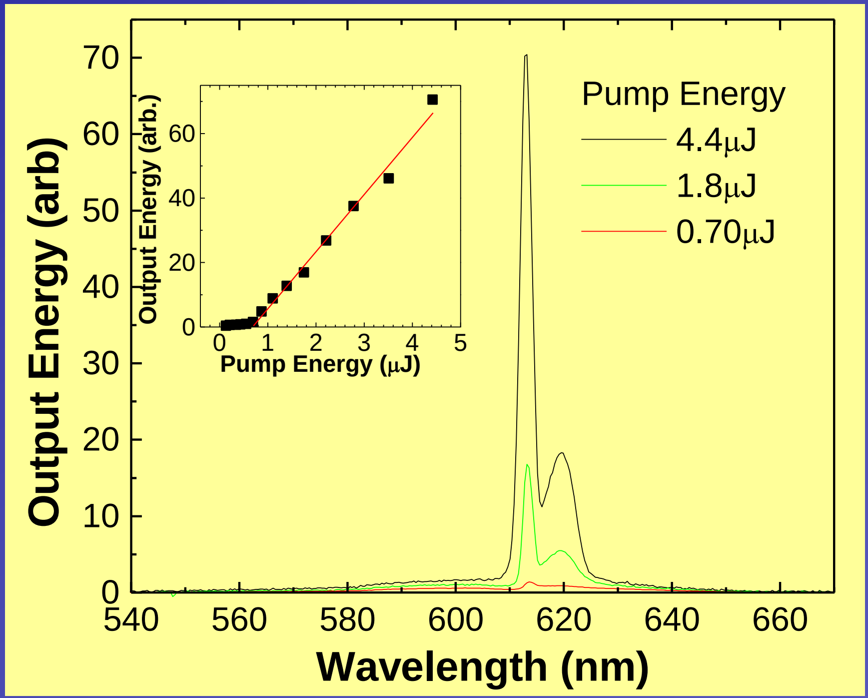
DFB lasing in an MEH-PPV film

1st order scattering provides output coupling

2nd order scattering provides distributed feedback

DFB Laser Operation





Light scattered from counter-propagating guided waves interfere to favour oscillation only at one band-edge

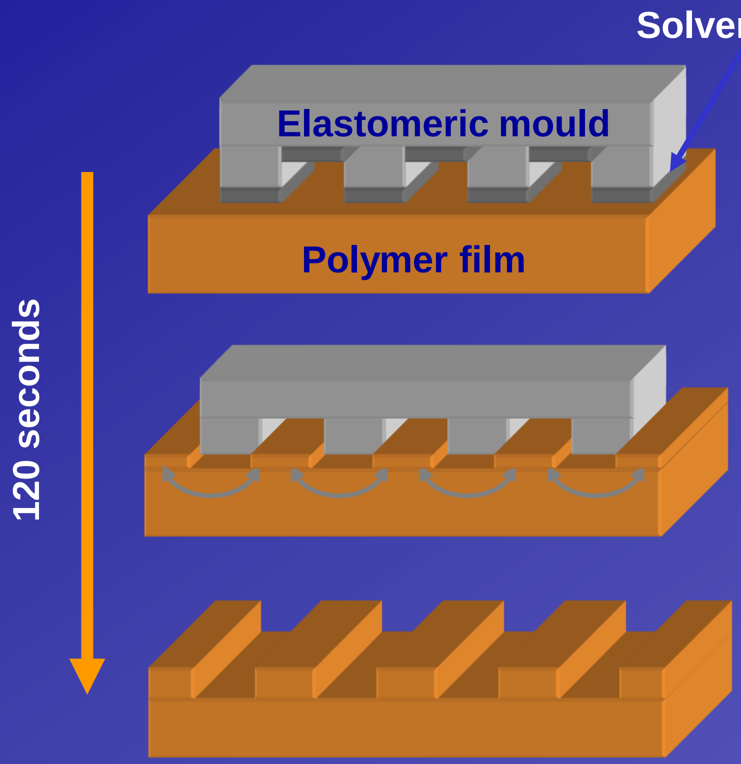
At high powers emission spectrum is dominated by laser mode and ASE

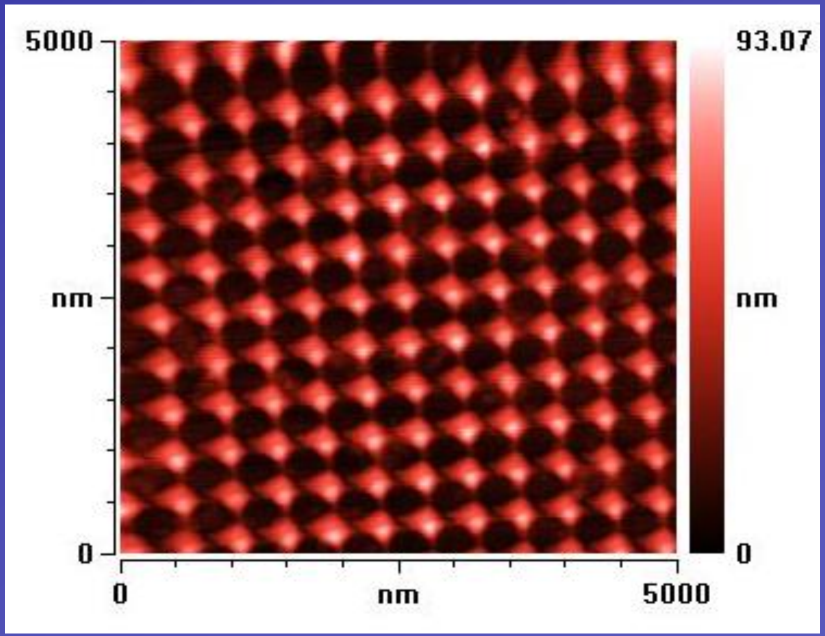
Simple Fabrication of Polymer Nanostructures

Hot embossing

Solvent assisted micro-moulding

UV-nanoimprint lithography





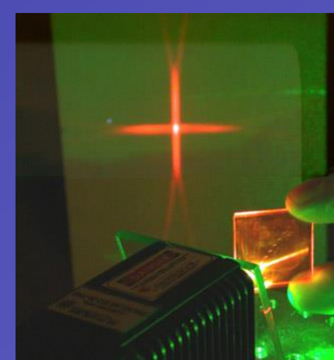
AFM image of 400 nm period, 90 nm deep eggbox corrugation

Appl Phys Lett 81, 1955 (2002); Appl Phys Lett 82, 4023 (2003);

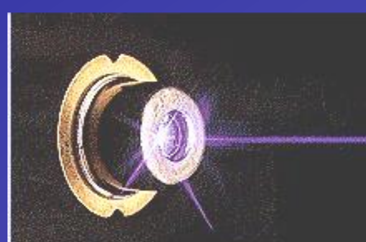
Towards Practical Polymer Lasers: Shrinking Polymer (Pump) Lasers

1995 Regenerative amplifier

~2000 Q-switched Nd:YAG



2004 Microchip laser



2006 Diode pumped

Electrically Pumped Organic Lasers?

commentary

How to recognize lasing

Ifor D. W. Samuel, Ebinazar B. Namdas and Graham A. Turnbull

The race to demonstrate new lasers, including electrically pumped polymer lasers, makes it a good time to reflect on the measurements that must be undertaken to support a claim of lasing.

Main Challenges

High projected threshold current density (> 100s A/cm^2)

Low carrier mobilities

Losses from metal contacts

Polaron and triplet absorption losses

http://en.wikipedia.org/wiki/Laser

Chemical Reviews **107** 1272 (2007); Nature Photonics **3**, 546 (2009)

Towards LED Pumped Polymer Lasers: Hybrid Optoelectronics

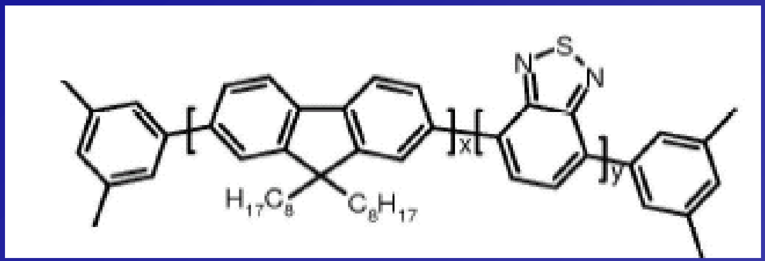
Alternative approach: indirect electrical pumping

- Take advantage of advances in nitride semiconductors
- Inject charge and generate light in nitride LED
- Gives all advantages of direct injection, without problems

Challenges

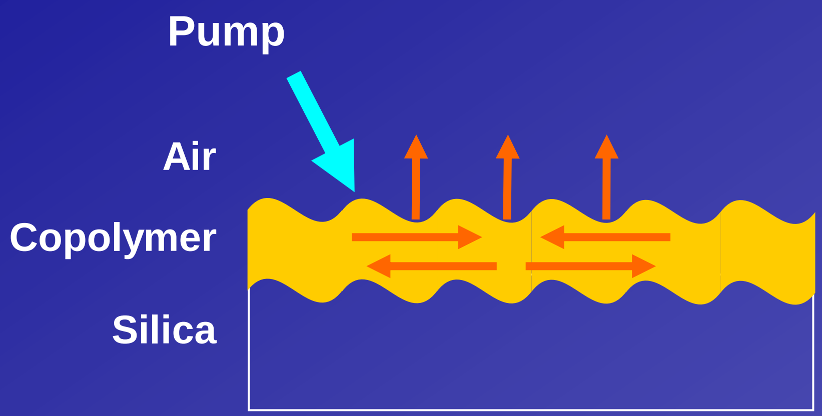
- Incoherent source
- Pulsed behaviour not known

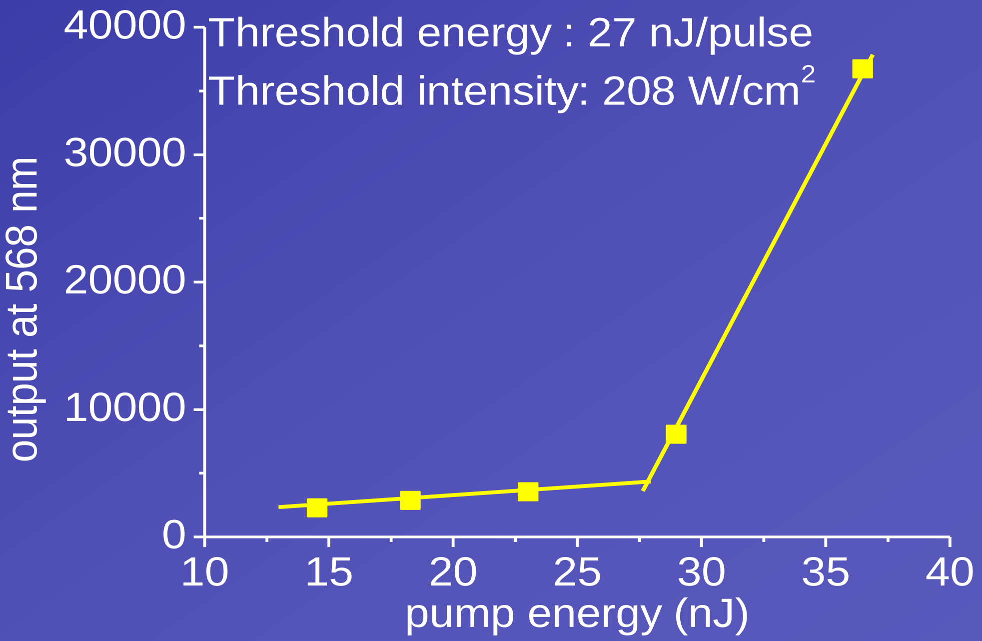
Low Threshold Polymer Laser: Structure and Characteristics



Fluorene copolymer

1-D Distributed feedback resonator, 350 nm period



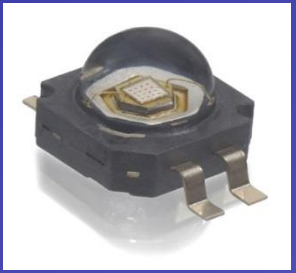


- Laser peak: 568 nm
- Lasing threshold: 208 W/cm^2

LED-Pumping of Polymer Lasers

Pumping source: inorganic LED

- Lumiled K2 emitter (LXK2-PR14-Q00)

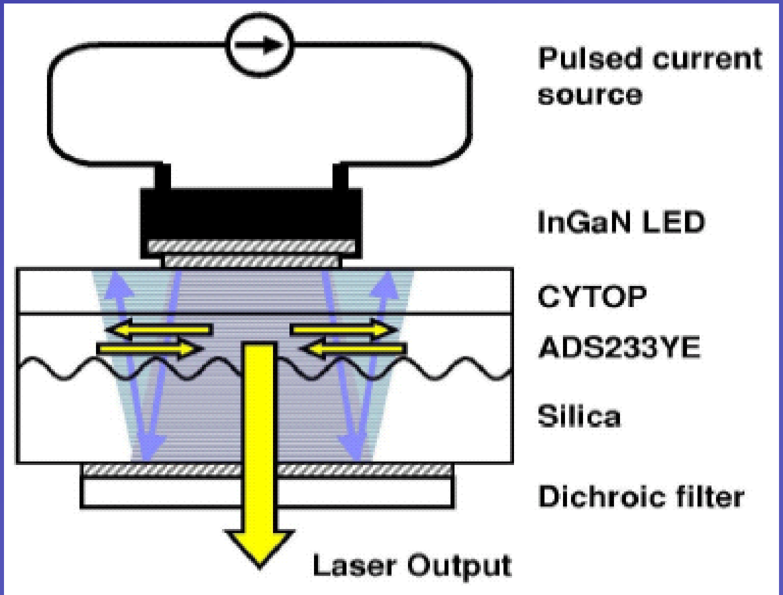


Lasers: organic gain medium

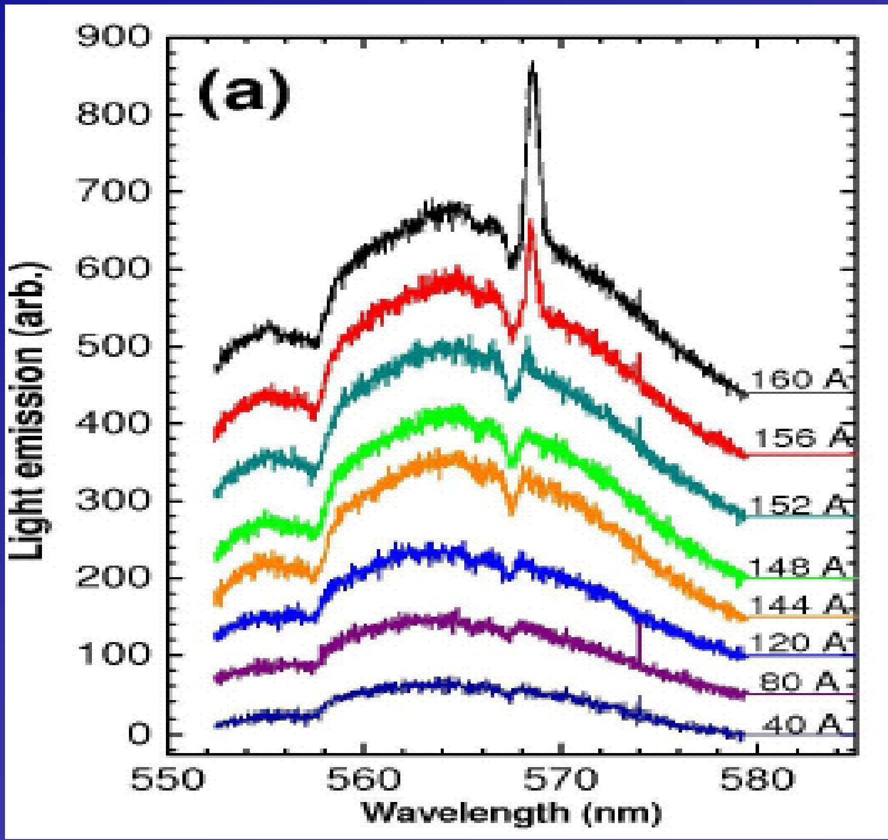
- 1D DFB surface emitting laser
- Fluorene copolymer

Device: compact

- LED in contact with laser
- Dichroic filter: reflect pump light
- CYTOP: encapsulation



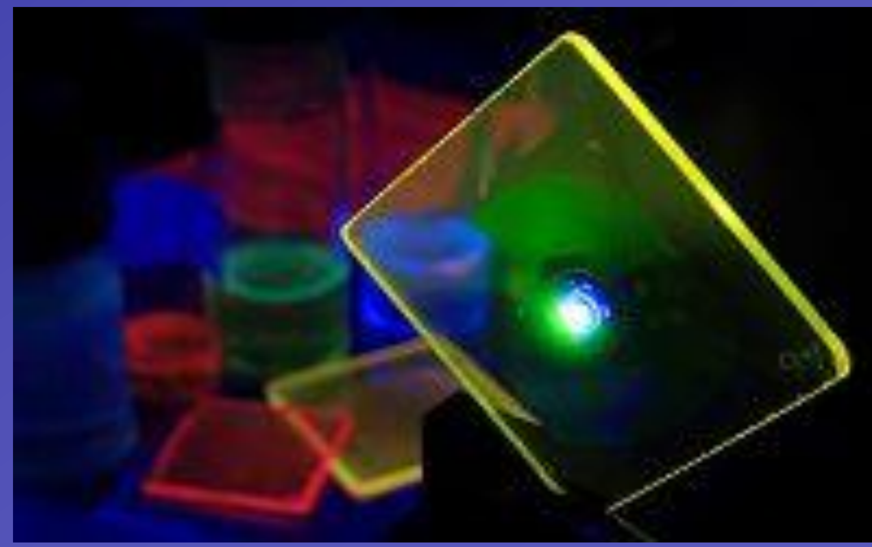
A Nitride LED Pumped Polymer Laser



NEWS & VIEWS NATURE|Vol 453|22 May 2008

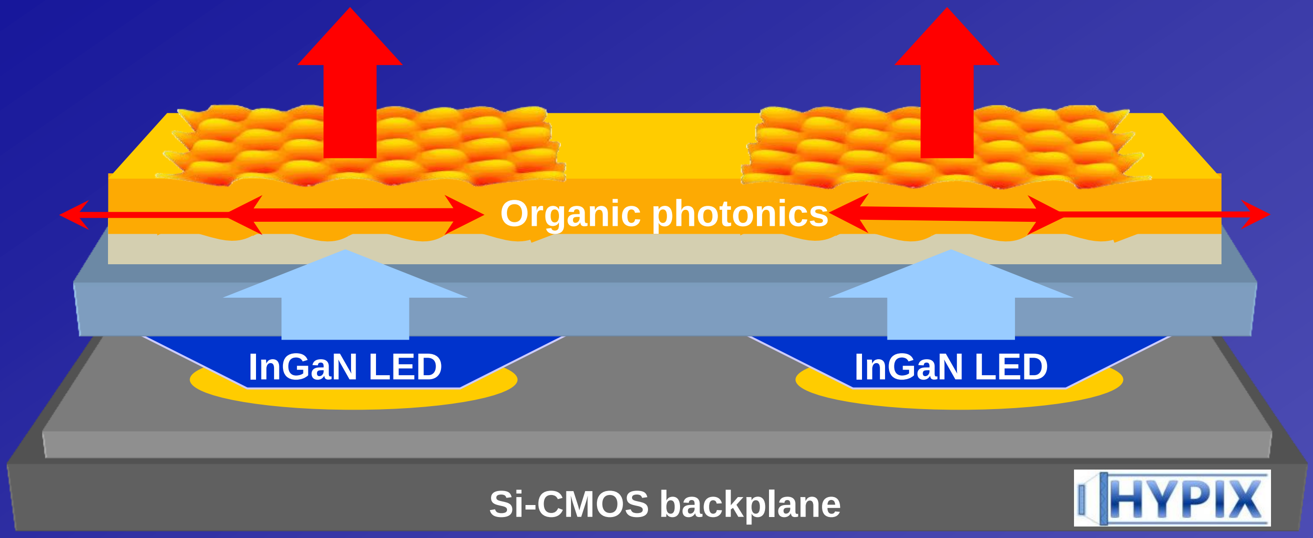
LASER TECHNOLOGY

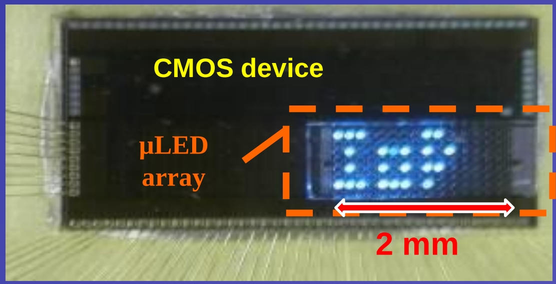
Over the rainbow

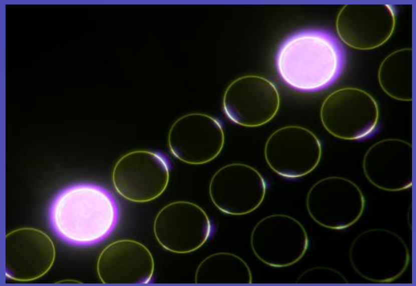


Sharp laser peak starts to form at
152 A (233 W/cm^2)
At 568 nm (TE mode): nonlinear increase
At 555 nm (TM mode): linear increase

HYPIX project



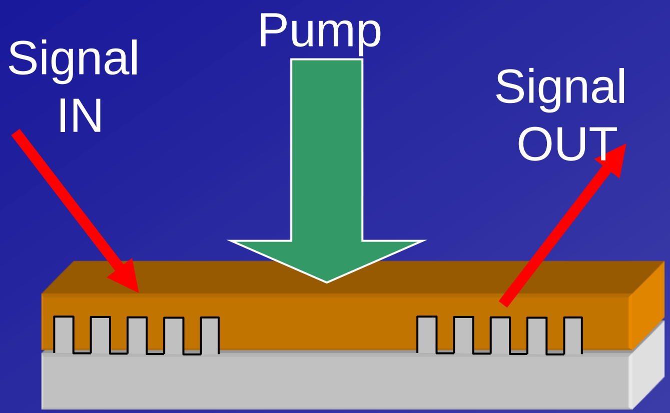




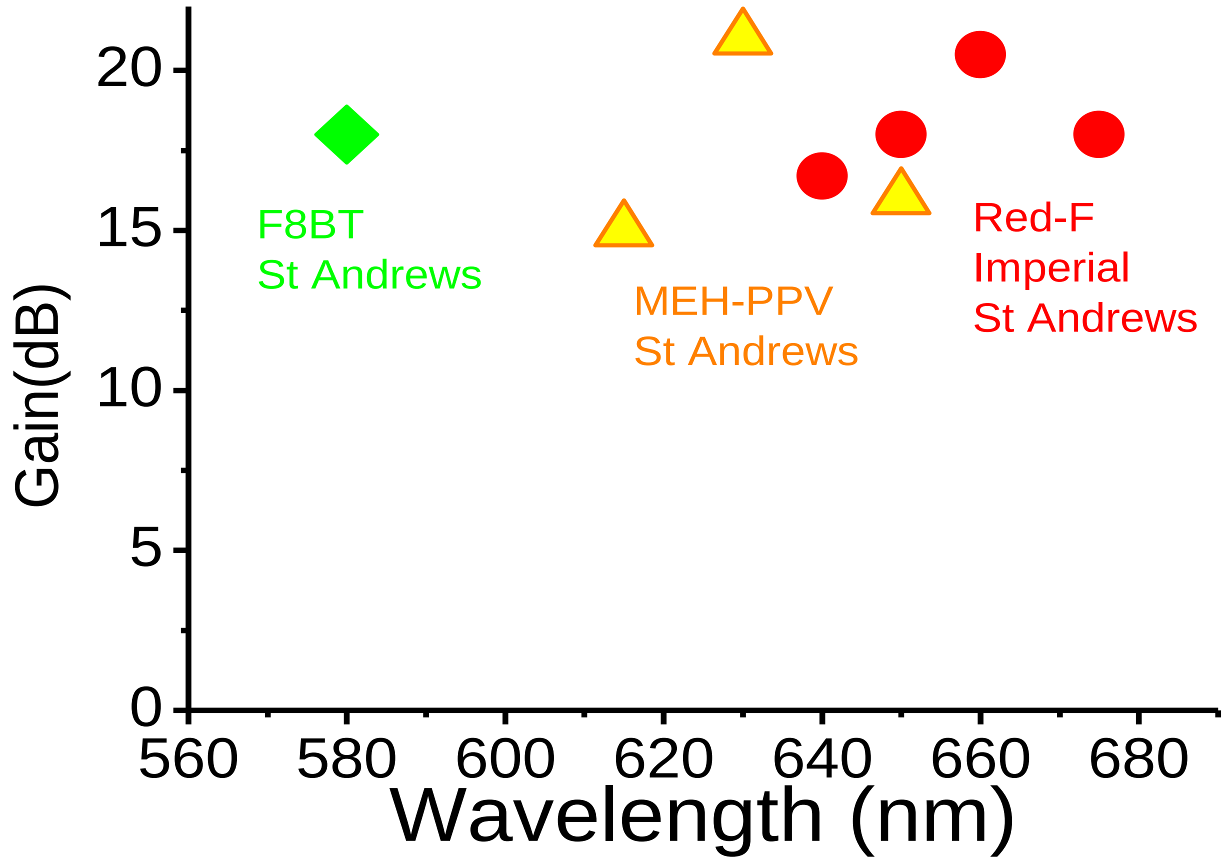
Hybrid organic semiconductor-GaN-CMOS smart pixel arrays

(St Andrews, Strathclyde, Edinburgh, Imperial College)

Solid State Polymer Amplifiers



Grating coupled



Gain up to 21 db: signal amplified 100 times

Wide wavelength range

Explosives Detection

Urgent need to detect explosive devices in war zones, airports

Metal detectors, ground penetrating radar to spot bombs

Sense vapours of explosives around bomb

Humanitarian demining

TIRAMISU

tiramisu.eu

Toolbox Implementation for Removal of Anti-personnel Mines, Submunitions and Uxo

What's in the toolbox

1) Land Impact Survey
tools enabling the prioritisation of the areas most affected and the efficient use of the other modules in a given situation

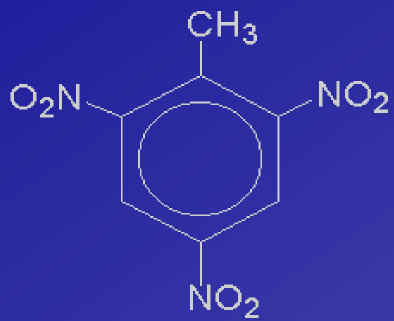
2) Non-Technical Survey & Advanced General Survey
tools to facilitate land release

3) Technical Survey
tools to detect indicators of probable presence of landmines/UXOs.

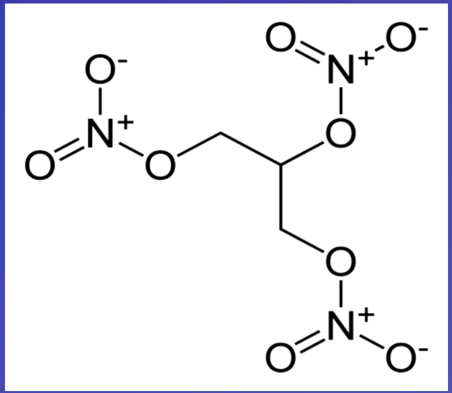
4) Ground-based Close-in Detection
tools, such as advanced metal detectors, Ground Penetrating Radars and novel chemical sensors.

Explosive molecules

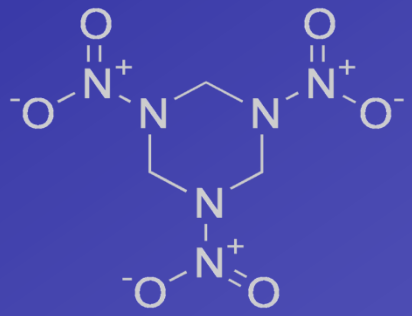
TNT

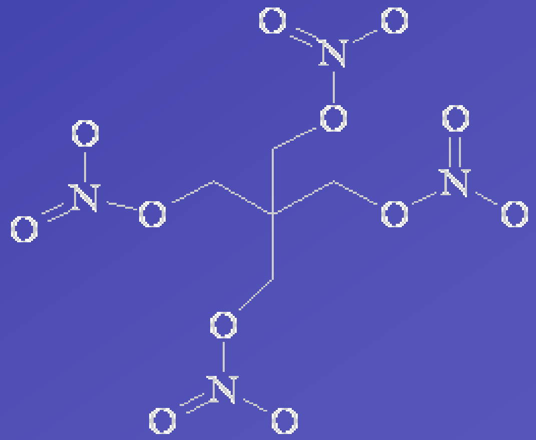


Dynamite: trinitroglycerine



Semtex: RDX and PETN

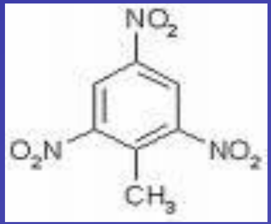




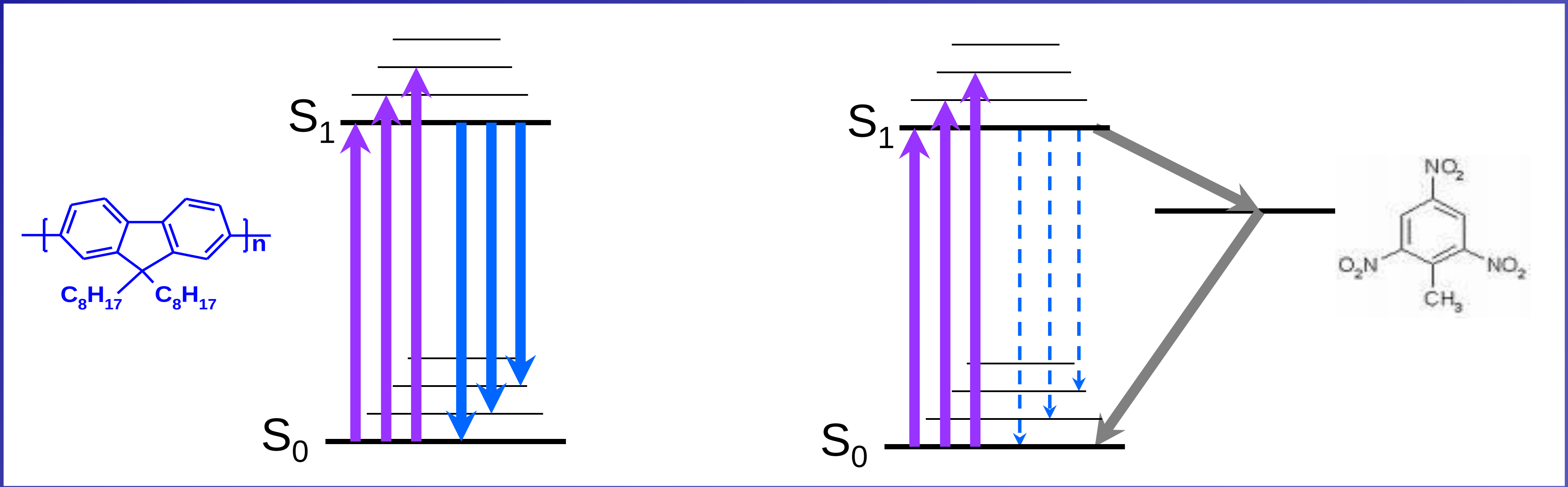
Fluorescent Explosives Detection

Many common explosives include TNT, DNT, DNB etc

Nitroaromatic compounds are strong electron acceptors



TNT



Introduction of nitroaromatic molecule leads to dissociation of exciton and quenches emission

Detect by fluorescence change Swager et al. *Chem. Rev.* **107**, 1339 (2007) or

Lasing change Rose et al *Nature* **434**, 877 (2005)

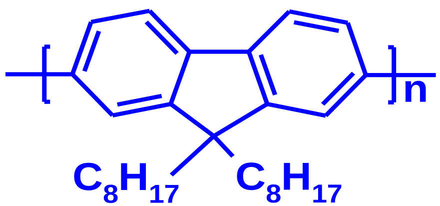
Fluorescence Sensing with Polyfluorene

Polyfluorene film exposed to ~10 ppb dinitrobenzene vapour in air

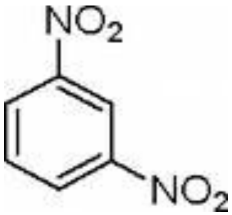
15% drop in fluorescence

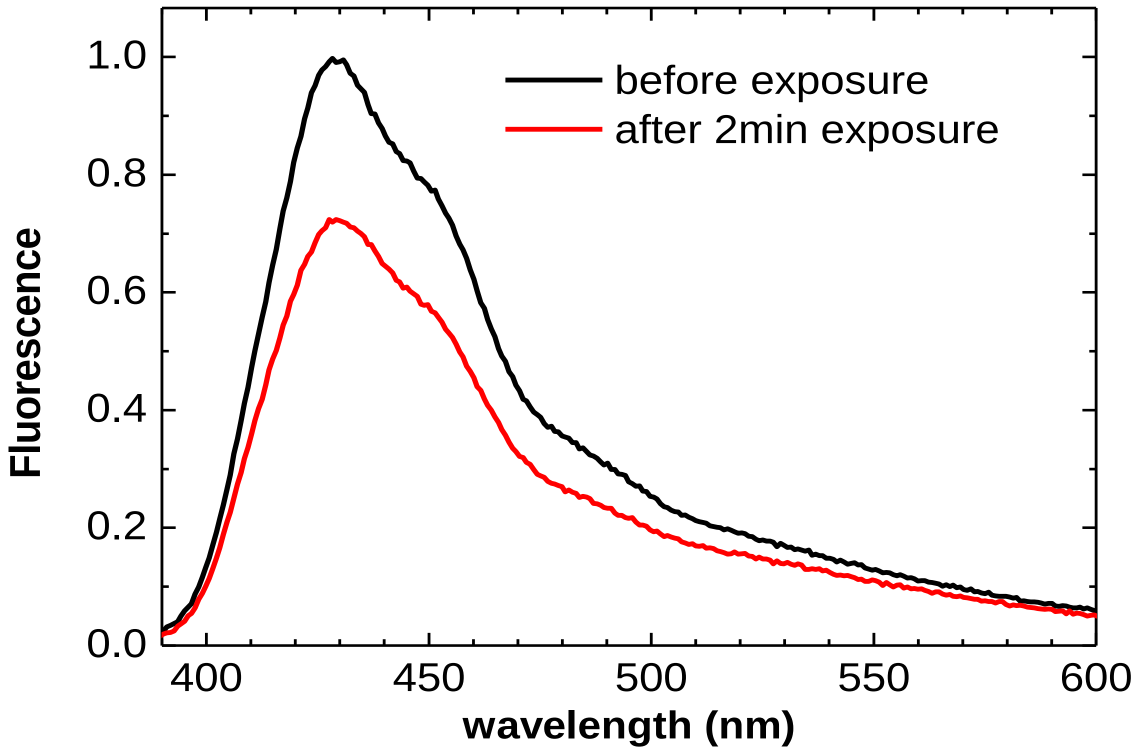
Fluorescence recovers to original value when purged in nitrogen

PFO



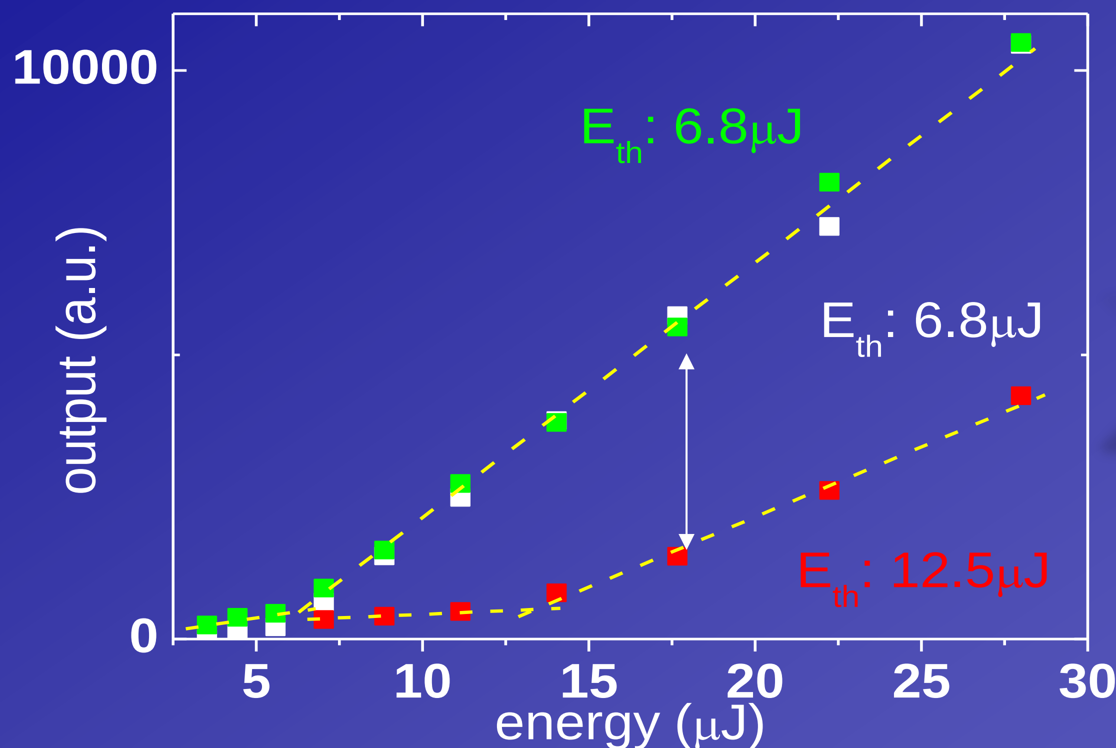
DNB

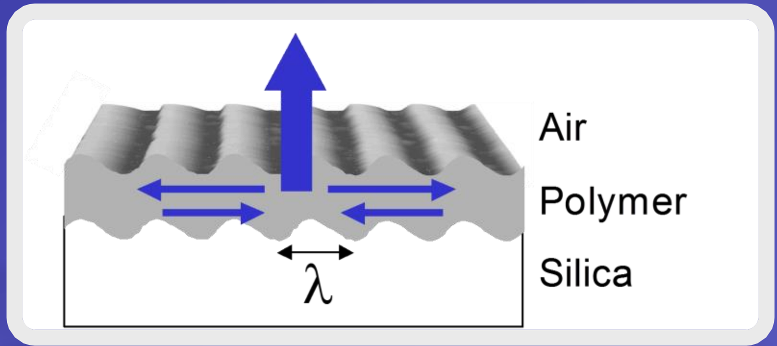




Explosive Vapour Sensor – Change of Slope Efficiency

Laser output before exposure to ~10 ppb DNB (green), after exposure (red), and after removal of DNB (white)





Slope efficiency 3 times lower

Threshold 1.8 times higher

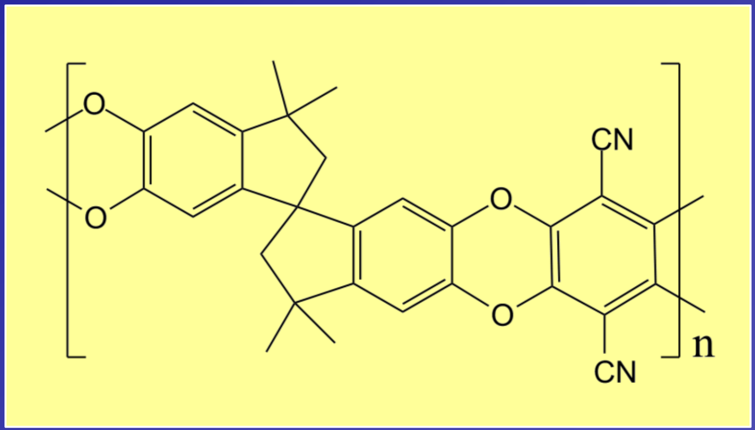
After 5 minutes exposure

Yang *et al*., Adv. Fun. Mat (2010); See also Rose et al *Nature* **434**, 877 (2005)

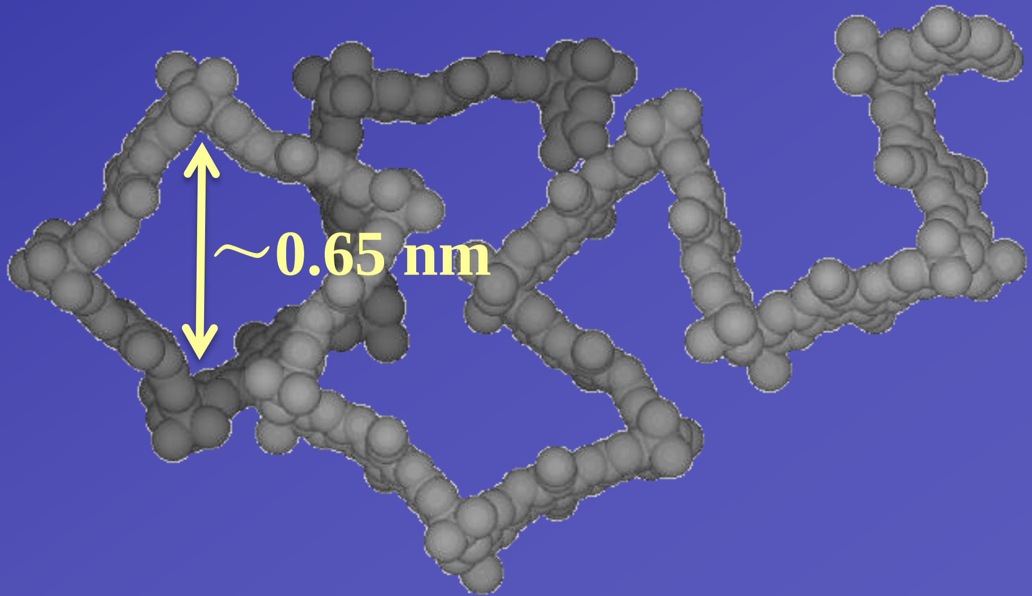
Sensing with Polymer of Intrinsic Microporosity

Could a porous material give a faster response?

Microporosity of the polymer PIM-1 forms as a result of the rigidity of the macromolecular chain and contorted structure



PIM-1



Collaboration with N.B. McKeown & K.J. Msayib, Cardiff

Comparison between PIM-1 and PFO sensors

- PL sensing efficiency 15 min

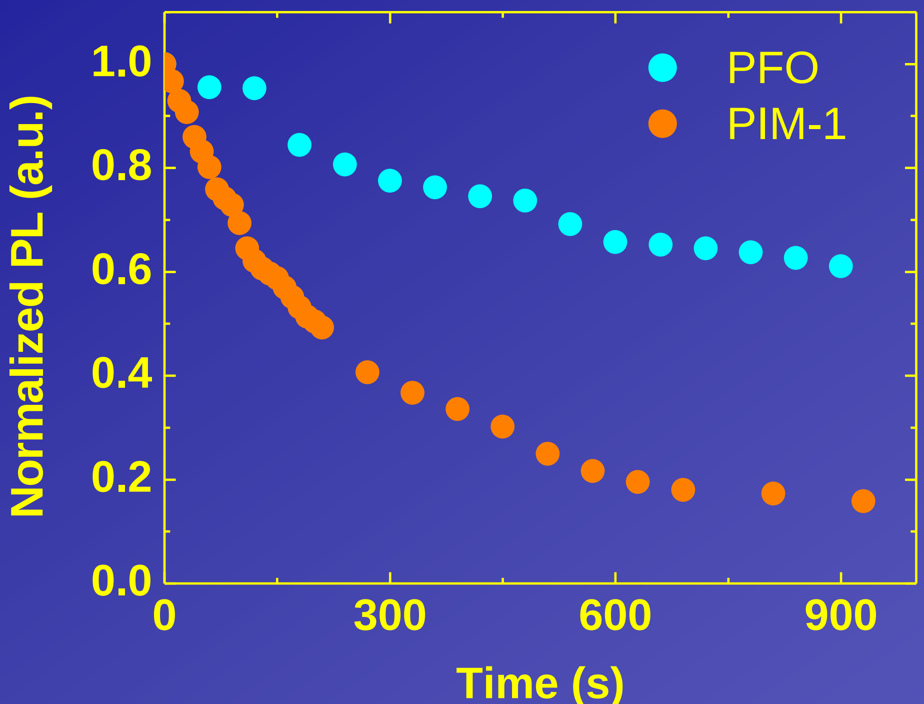
PFO: 40%

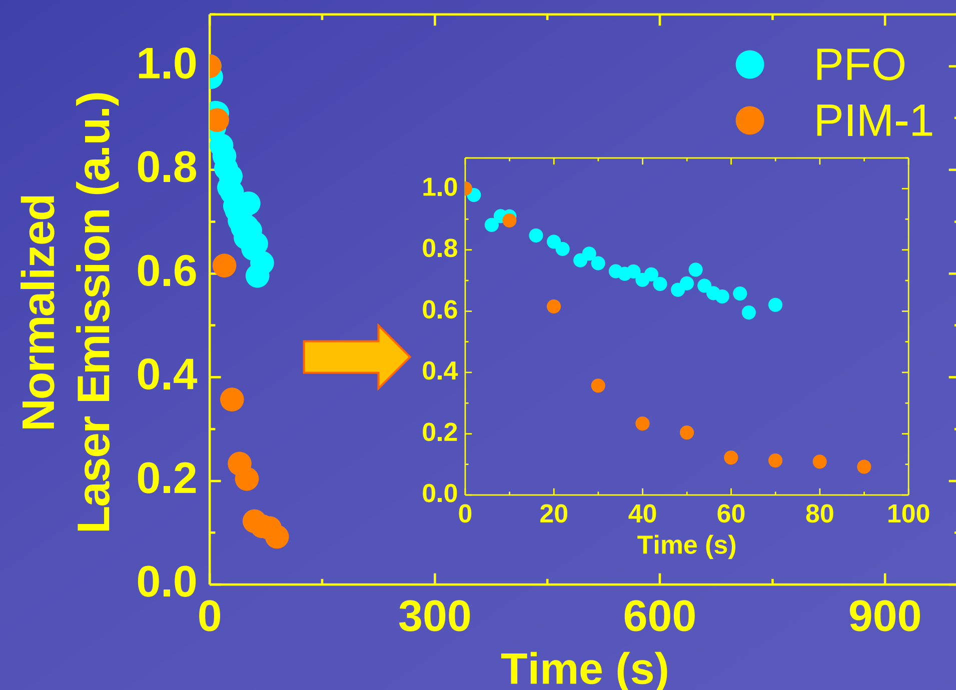
PIM-1: 82%

- Laser sensing efficiency 1 min

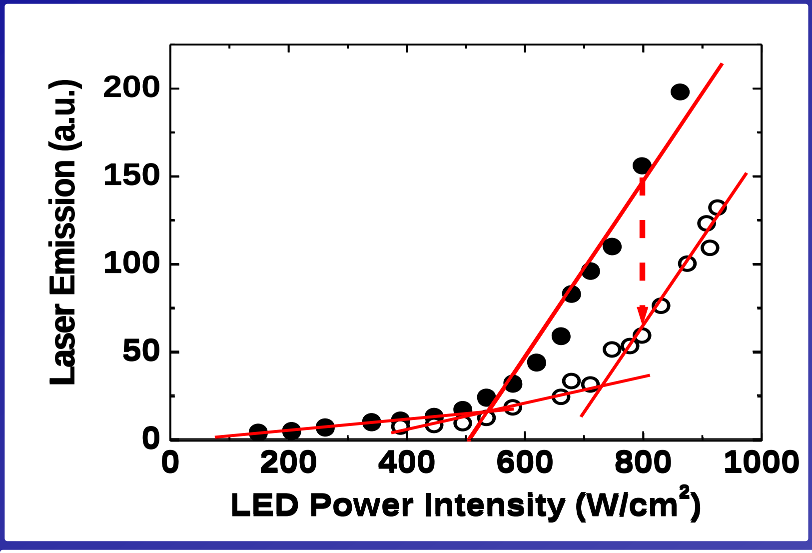
PFO: 36%

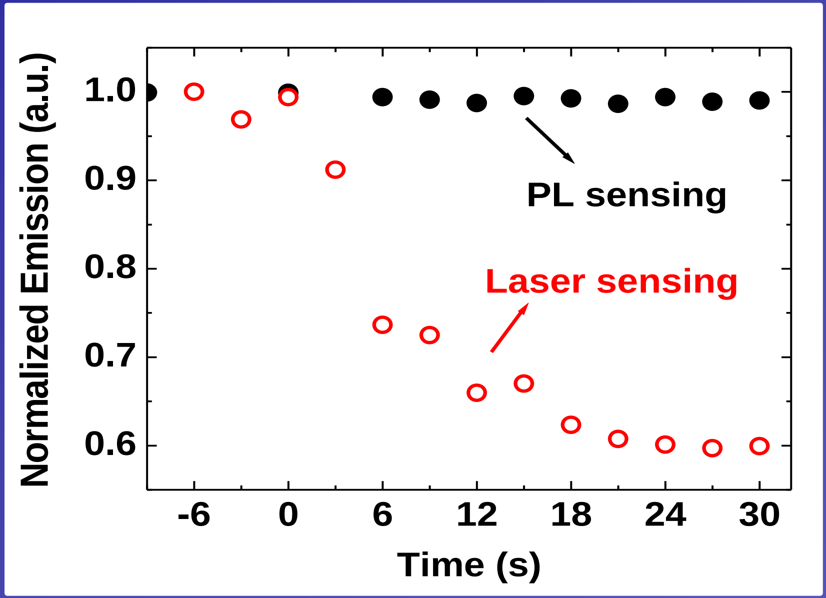
PIM-1: 88%





LED Pumped Organic Laser Sensor





- Laser exposed to 10 ppb DNB vapour for 90 s
- Before exposure, laser threshold: 535 W/cm^2 (32 A/pulse)
- After exposure, laser threshold: 711 W/cm ^{2} (50 A/pulse) 1.4 times higher
- Laser emission drops by 30% in 10 s (@ 61 A/pulse)
- Much higher sensitivity compared to PL

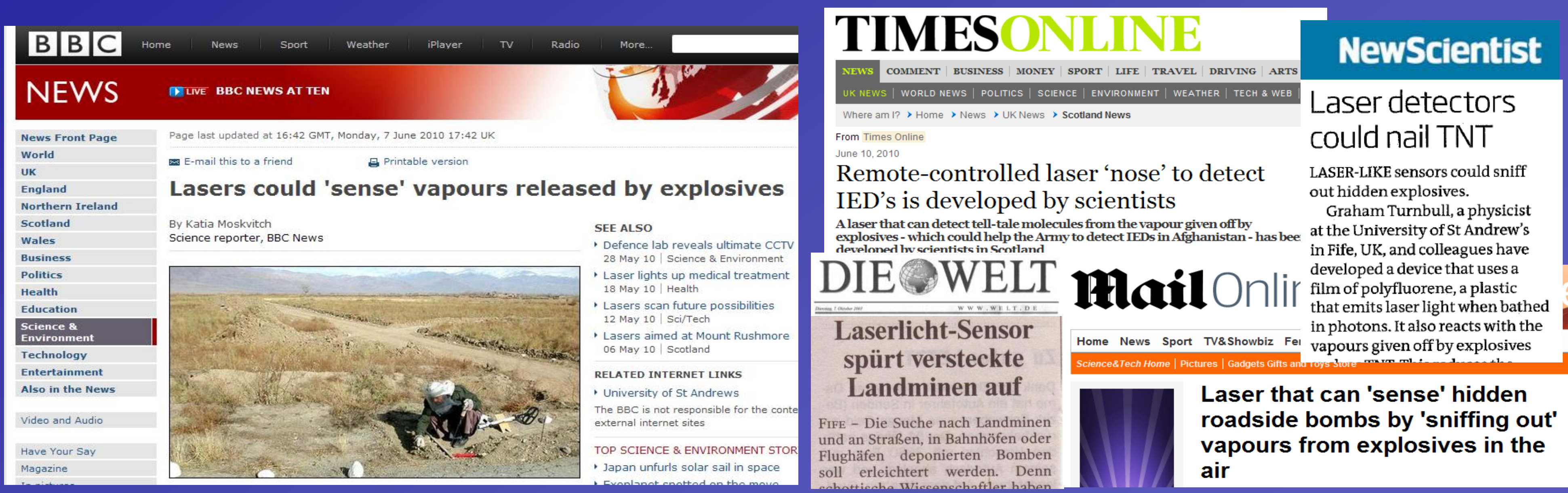
Polymer Laser Explosives Sensor

Potential for IED / landmine detection

Sensitivity to ppb nitroaromatic explosive vapours

Larger, faster response for lasers than PL

LED-pumped laser sensor demonstrated



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Lasers could 'sense' vapours released by explosives

By Katia Moskvitch
Science reporter, BBC News

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From Times Online
June 10, 2010

Remote-controlled laser 'nose' to detect IED's is developed by scientists

A laser that can detect tell-tale molecules from the vapour given off by explosives - which could help the Army to detect IEDs in Afghanistan - has been developed by scientists in Scotland

NewScientist

Laser detectors could nail TNT

LASER-LIKE sensors could sniff out hidden explosives.

Graham Turnbull, a physicist at the University of St Andrew's in Fife, UK, and colleagues have developed a device that uses a film of polyfluorene, a plastic that emits laser light when bathed in photons. It also reacts with the vapours given off by explosives

DIE WELT

Laserlicht-Sensor spürt versteckte Landminen auf

FIFE – Die Suche nach Landminen und an Straßen, in Bahnhöfen oder Flughäfen deponierten Bomben soll erleichtert werden. Denn

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Laser that can 'sense' hidden roadside bombs by 'sniffing out' vapours from explosives in the air

Organic Semiconductor Lasers : Conclusion

Compact, tuneable visible lasers

Simple fabrication

Direct pumping by InGaN LED

Explosive sensing

Further reading *Chemical Reviews, Nature Photonics*