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
Absorption and emission separated - 4 level system

Strong absorption $\sim 10^5$ cm$^{-1}$
- Enormous gain

Little concentration quenching

Broad spectra - broad bandwidth

Compatible with polymer fibre transmission windows (500–560 and $\sim 660$ 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

Pump laser: 500ps pulses at 500nm
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

**Diagram:**
- Elastomeric mould
- Polymer film
- Solvent
- AFM image of 400 nm period, 90 nm deep eggbox corrugation

Applied Physics Letters 81, 1955 (2002); Applied Physics Letters 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?

Main Challenges

- High projected threshold current density (> 100s A/cm²)
- Low carrier mobilities
- Losses from metal contacts
- Polaron and triplet absorption losses

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

- Laser peak: 568 nm
- Lasing threshold: 208 W/cm²

Fluorene copolymer
1-D Distributed feedback resonator, 350 nm period

Threshold energy: 27 nJ/pulse
Threshold intensity: 208 W/cm²

Output at 568 nm
Pump energy (nJ)

Air
Copolymer
Silica

Distributed feedback resonator, 350 nm period
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

Sharp laser peak starts to form at 152 A (233 W/cm²)
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

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

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.

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

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

Explosive Vapour Sensor – Change of Slope Efficiency

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.

\[ \text{PIM-1} \]

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
Organic Semiconductor Lasers: Conclusion

Compact, tuneable visible lasers
Simple fabrication
Direct pumping by InGaN LED
Explosive sensing

Further reading Chemical Reviews, Nature Photonics