Organic Opto - Electronics Summer School
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Organic Lasers
introductory course

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Outline

- Introduction: back to laser basics
- Fundamentals of organic lasers: the gain medium
- Organic laser resonators
- From optical pumping to electrical pumping?
- Novel concepts for organic lasers
A brief history of organic lasers

- **1960**: 1st laser (T. Maiman, in ruby crystal)
- **1966**: 1st liquid dye laser (Sorokin, Schafer)

“Dye lasers allowed a long pursued dream to be realized: to obtain a laser that was easily tunable over a wide range of frequencies”

M. Bertolotti, The History of the Lasers
IOP publishing, 1999
A brief history of organic lasers


- **1974**: Lasing in organic crystals (Karl, *fluorene organic crystal doped with anthracene*)

- **1970-90**: Industrial development of liquid dye lasers

- Narrow linewidth (~ 0.01 nm) and broad tunability

- Bulky, and Handling / maintenance issues...
  - Toxic dyes (some of them are carcinogenic) and unfriendly solvents (methanol)
  - Frequent replacement of the solution is required
A brief history of organic lasers

90’s: rebirth of organic lasers with Organic SemiConductors

1996: 1st organic semiconductor laser


- Quest for the electrically-pumped organic laser diode
  - Optically-pumped organic thin-film solid-state lasers
  - Physics: dynamics of gain...
  - Applications: diode pumping...

A brief history of organic lasers

2000: Schön’s breakthrough huge fraud

An organic solid state injection laser

- Substitution of data (substitution of whole figures, single curves and partial curves in different or the same paper to represent different materials, devices or conditions)
- Unrealistic precision of data (precision beyond that expected in a real experiment or requiring unreasonable statistical probability)
- Results that contradict known physics (behavior inconsistent with stated device parameters and prevailing physical understanding, so as to suggest possible misrepresentation of data)

2003: compact organic laser pumped by microchip laser
2006: diode-pumped organic laser
**2008**: 1st LED-pumped organic laser (Samuel)
2010: organic polariton laser (Forrest)
2011: first start-up company on organic solid-state lasers (Visolas)
Back to laser basics
What is a laser?

A LASER is a source of **COHERENT** light

To make a laser you always need **these 3 building blocks**:

- **a gain medium** (here a $\pi$-conjugated organic compound): amplifies optical waves
- **a resonator**: creates feedback and defines the laser modes
- **a pumping system**: creates the population inversion required to obtain amplification
Basics of laser operation

• Principle of stimulated emission (Einstein, 1917)

- Amplification of optical waves requires a population inversion between two states

2-level system

Doesn’t work!

4-level system

\[ \Delta N = N_2 - N_1 > 0 \]
The resonator

The resonator enhances the amplification (multiple passes) and defines the **photon modes**: frequency and spatial characteristics

Simplest resonator = the **Fabry Perot**

Only waves replicating in phase after one round trip exist: **the cavity modes**

https://www.youtube.com/watch?v=R_QOWbkc7UI

Laser condition: **Gain > Losses**
(roundtrip)
The resonator

The electromagnetic mode pattern must be self-replicating after one round trip in the resonator.

Ex: standard 2-mirror cavity: the beam shape and divergence is governed by cavity length and the mirrors’ radius of curvature.
Laser = optical wave oscillator

Gain saturation is naturally provided by stimulated emission.

A gain saturation mechanism is mandatory to stabilize the amplitude of oscillations in an electronic oscillator.
Fundamentals of organic lasers
Key features of Organic Solid-state Lasers

**ORGANIC**
- Broadly tunable in the visible range
  - chemical design
  - broad fluorescence spectra (~100 nm)
- Low cost and versatile techniques
  - Large area, solution processing
- Electrical excitation of Organic semiconductors?
  - Photodegradation 😞

**SOLID-STATE**
- Compact, down to the nanoscale
- User-friendly
- Compatible with existing technological platforms:
  - waveguides
  - coupling to plastic optical fibers
  - biocompatible

**LASERS**
- High brightness
- spectral purity
- highly nonlinear response
- spectroscopy, chemical or biological sensing, short-haul data communication s...
What makes a laser different?

(OSSLs versus OLEDs)

✓ **A laser has a narrow spectrum** (or temporal coherence, defined by resonator, in general < a few nm) : useful for e.g. **spectroscopy**

See examples in next talk by U. Lemmer
What makes a laser different?
(or: what can we do with organic lasers?)

✓ A laser has a clear threshold: nonlinear response can be used in sensing applications.

S. Richardson et al., Appl. Phys. Lett. 95(6), 063305 (2009)
What makes a laser different?  
(organic lasers vs. OLEDs)

Lasers are not remarkable for their high power, but for their high brightness

\[
Brightness = \frac{Power}{Emission \ area \times solid \ angle} = \frac{P}{A \times \Omega}
\]

High brightness = «ray»-like beam = usable beam (can be focussed, directed, coupled to an optical fiber, etc.)

**OLEDS**
- Large area, lambertian source \((\Omega=2\pi)\)
- Brightness \(\sim 100 \text{ cd/m}^2\) to 10 \(\text{Mcd/m}^2\) (max, ns pulsed regime)

**Organic laser**
- small area (<mm\(^2\)), diffraction-limited divergence\((A \times \Omega = \lambda^2)\)
- Energy per pulse from pJ to µJ, ns duration

\[B_{\text{OLED}} \sim 10^0 - 10^6 \text{ W/m}^2/\text{sr}\]
\[B_{\text{OSSL}} \sim 10^9 - 10^{15} \text{ W/m}^2/\text{sr}\]
Energy level diagrams

\[ S_n \]

+polaron states in conjugated polymers

This needs a bit of simplification to work with!
Simplified Jablonski diagram

Transition rates ($s^{-1}$) for one molecule:

**Pump rate:** $\sigma_{abs} I_p$

$\sigma_{abs} = $ absorption cross section ($cm^2$)

$I_p = $ pump intensity (photons/s/cm$^2$)

**Spontaneous emission rate:**

$$\frac{1}{\tau} = \frac{1}{\tau_{rad}} + \frac{1}{\tau_{nr}} + k_{ISC} = \frac{1}{\phi_F \tau_{rad}}$$

$\phi_F = $ quantum yield of fluorescence

**Stimulated emission rate:** $\sigma_{em} I$

$\sigma_{em} = $ emission cross section ($cm^2$)

$I = $ laser intensity inside the cavity (photons/s/cm$^2$)

Typical orders of magnitude:

$\sigma_{abs} \sim \sigma_{em} \sim 10^{-16} cm^2$

$\tau \sim ns$

$k_{IC}^{-1} \sim ps$
Simplified Jablonski diagram

\[
\begin{align*}
S_1 & \quad \text{k}_{\text{ISC}} \\
\sigma_{\text{abs}} I_p & \quad \frac{1}{\tau_{\text{rad}}} \quad \frac{1}{\tau_{\text{nr}}} \quad \sigma_{\text{em}} I \\
S_0 & \quad \text{k}_{\text{IC}}
\end{align*}
\]

Typical orders of magnitude:

\[
\begin{align*}
\sigma_{\text{abs}} & \sim \sigma_{\text{em}} \sim 10^{-16} \text{ cm}^2 \\
\tau & \sim \text{ns} \\
k_{\text{IC}}^{-1} & \sim \text{ps}
\end{align*}
\]

\[
k_{\text{IC}} \gg \frac{1}{\tau}, \sigma_{\text{em}} I \Rightarrow \Delta N = S_1
\]

✓ A 4-level system at first glance

✓ Absorption and emission cross sections are among the highest of all laser media

✓ Short \( \tau \): difficult to maintain a population inversion
Note: all decay rates compete with each other

\[
\frac{\text{Number of stimulated photons}}{\text{Total number of emitted photons}} = \frac{\sigma_{em} I}{\sigma_{em} I + \frac{1}{\phi_F \tau_{rad}}} = \frac{\frac{I}{I_{\text{sat}}}}{1 + \frac{I}{I_{\text{sat}}}}
\]

\[\sigma_{em} I_{\text{sat}} = \frac{1}{\tau} \quad \text{(photonic units)}\]

\[\rightarrow \text{1 if } I \gg I_{\text{sat}} \quad ; \quad \text{Typical order of magnitude: } I_{\text{sat}} \sim \text{MW/cm}^2\]

⇒ Counter-intuitive fact: stimulated emission can occur even in very poorly fluorescent compounds

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**Imaging chromophores with undetectable fluorescence by stimulated emission microscopy**

Weimin, Sijia Lu, Shasha Chong, Rahul Roy, Gary R. Holton & X. Sunney Xie

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**Figure 3** Imaging non-fluorescent chromoproteins and chromogenic reporter for gene expression. Imaging distributions of cytoplasmic chromoproteins gCp (a) and cBlue (c) in live E. coli cells, respectively, by stimulated emission microscopy. b and d are the corresponding wide-field...
The emission cross section

In a perfect 2-level system \( \sigma_{\text{abs}} = \sigma_{\text{em}} \) (Einstein)

In pi-conjugated systems (broad spectra, approx. 4-level), the **Strickler-Berg** relations apply:

\[
\sigma_{\text{em}}(\lambda) = \frac{\lambda^4}{8\pi cn_F^2 \tau_{\text{rad}}} \frac{f(\lambda)}{\int f(\lambda) \, d\lambda}
\]

- \( f(\lambda) \) normalized PL spectrum
- \( n_F \) average index of refraction at fluorescence wavelengths
The unsaturated gain

Small-signal gain

\[ \frac{dI}{dz} = g_{\text{net}} I \]

Net gain:

\[ g_{\text{net}}(\lambda) = g(\lambda) - \alpha(\lambda) \]

\[ = \sigma_{em}(\lambda) S_1 - \sigma_{abs}(\lambda) S_0 - \sigma_{abs}(\lambda) S_1 - \sigma_{TT}(\lambda) T_1 \]

Unit for \( g \) : cm\(^{-1}\)

\[ I(L) = I_0 \exp(g_{\text{net}} L) \]
Measuring gain: pump-probe techniques

ns pump/CW probe experiment

DCM:PMMA film on glass

CW probe (HeNe @ 594 nm)

Figure 2: Pump-probe set-up for measuring the material gain $g_{mat}$. (a) Continuous probe beam. (b) Sample. (c) Amplified probe beam. (d) Monochromator. (e,h,i) Photodiodes. (f) Pulsed pump beam. (g) Glass slide.

CW probe = noninvasive measure of unsaturated gain: $I_{probe} \ll I_{sat}$

I. Gozhyk et al., submitted (arXiv:1403.7461)
Measuring gain: the Variable Stripe Length (VSL) technique

\[ I(L) = \frac{\eta_{spont}}{g-\alpha} \left[ e^{(g-\alpha)L} - 1 \right] \]

- No gain, no loss: spontaneous emission
- Gain > Losses: Amplified Spontaneous Emission (ASE)
- Gain < losses

Organic thin film

Low-index substrate

Pump stripe

Light from the edge

Gain > Losses: Amplified Spontaneous Emission (ASE)

Gain < losses

No gain, no loss: spontaneous emission

Spectrum ~ 10 nm FWHM

ASE = « mirrorless lasing »

Fluorescence

ASE

Laser

Normalized intensity

Wavelength (nm)
Measuring gain: the Variable Stripe Length (VSL) technique

The VSL technique is widely used to characterize organic thin films as it is simple to implement, but:

- $I_{sat}$ is reached within a few mm of propagation only
- Losses have to be measured independently


*H. Rabbani-Haghighi et al., APL 95(3), 033305 (2009)*
Importance of triplet states for lasing

\[
\frac{dT_1}{dt} = k_{ISC} S_1 - \frac{T_1}{\tau_T} - \sigma_{TT} I T_1
\]

- Creation via intersystem crossing
- Slow decay (mostly nonradiative)
- Triplet-Triplet Absorption (TA)

Typical orders of magnitude:

\[k_{isc} \sim 10^6 - 10^8 \text{ } s^{-1}\]

\[\sigma_{TT} \sim 10^{-16} \text{ } cm^2\]

\[\tau_T \sim \mu s - \text{ s}\]
Importance of triplet states for lasing

Triplet absorption spectrally overlaps stimulated emission
Importance of triplet states for lasing
Experimental evidence of Triplet Absorption

PHYSICAL REVIEW B 81, 165206 (2010)

Impact of triplet absorption and triplet-singlet annihilation on the dynamics of optically pumped organic solid-state lasers

M. Lehnhardt, T. Riedl, T. Weimann, and W. Kowalsky

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(Received 16 February 2010; published 27 April 2010)

FIG. 2. (Color online) (a) Setup for TA measurement. (b) Decrease in edge emission at varied pump pulse duration and energy density for F8BT/MEH-PPV. Fitted values for the saturation over the pulse length (open circles) and an exemplary fit over the energy density (dotted line) for a pulse duration of 1 μs. (c) TA in pristine F8BT, pristine MEH-PPV, and F8BT/MEH-PPV.
Importance of triplet states for lasing

Major impact: Organic Solid-State Lasers are limited to PULSED OPERATION

DCM:PMMA laser: pulsewidth \(\sim 100\) ns

Z. Zhao et al., submitted

F8BT/MEHPPV polymer laser: pulsewidth \(\sim 3\) ns

M. Lehnhardt et al., PRB 81, 165206 (2010)
CW lasing?

Simplified condition assuming only Triplet Absorption, and neglecting $T_1$ depletion by laser absorption

$$\frac{dT_1}{dt} = k_{ISC} S_1 - \frac{T_1}{\tau_T} = 0 \text{ (steady state)}$$

$$\Rightarrow T_1^{CW} = k_{ISC} \tau_T S_1^{CW}$$

CW lasing requires: $g = \sigma_{em} S_1^{CW} - \sigma_{TT} T_1^{CW} > 0$

$$\Rightarrow k_{ISC} \tau_T < \frac{\sigma_{em}}{\sigma_{TT}}$$

Simplified CW lasing condition

Orders of magnitude: $\frac{\sigma_{em}}{\sigma_{TT}} \sim 1$; $k_{ISC}^{-1} \sim 100 \text{ ns}$; $\tau_T \sim \text{ms}$

Very difficult to achieve!

Expression for the typical pulsewidth expectable from an organic laser (same assumptions)

$$t_L \sim \frac{\sigma_{em}}{\sigma_{TT} k_{ISC}}$$

Experimental values: 
~100 ns (dyes)
~ns (conjugated polymers)
CW lasing?

Idea: to add a «triplet manager» molecule to enhance the triplet decay rate through intermolecular transfers.

FIG. 2. (Color online) (a) PL and (b) lasing transients measured at 1.6 kW/cm² pump intensity for different host blends. PL transients are normalized by the peak intensities, and lasing transients are normalized to 1 for $x = 0, 10,$ and 30 ADN blends and to 5 for $x = 50$ and 70 ADN blends. The fits are obtained by the model described in the text, with the parameters summarized in Table 1. The inset shows the lasing spectrum of an $x = 70$ OSL.
Comparing organic laser thresholds: in J/cm² or in W/cm²?

Many literature reports present comparisons of different materials based on their lasing performance: to make this comparison relevant, the resonator geometry and the pump pulse duration \( T_p \) must be as similar as possible.

- At constant pump intensity \( I_p \) (W/cm²), the characteristic loading time needed to reach steady-state inversion is \( \tau_{\text{eff}} \sim \tau \sim \text{ns} \) (< \( \tau \) for intense pumping)

\[
T_p < \tau_{\text{eff}} \quad \Rightarrow \quad \text{Laser is an energy storing device} = \text{use fluence (J/cm}^2\text{)}
\]

\[
T_p > \tau_{\text{eff}} \quad \Rightarrow \quad \text{Laser is an energy converting device} = \text{use power density (W/cm}^2\text{)}
\]

Simulation

Example of a VECSOL laser working as an energy converting device

H. Rabbani-Haghighi et al., The European Physical Journal Applied Physics, 56, 34108 (2011)
Materials for OSSLs (a few examples)

**Small molecules (dyes)**
Often used diluted because of concentration-induced aggregation/quenching

- **Coumarin** (generic)
- **Rhodamine** (generic)
- **Pyrromethene** (generic)
- **DCM**

**Organic crystals**
- **Anthracene**
- **DSB**

**Conjugated polymers**
- **PFO**
- **PPV**
- **F8BT**
- **Ladder-type MeLPPP**

Processing techniques: spin coating, dip coating, ink jet printing, thermal evaporation (small molecules), ...
Host/guest blends

**Förster (or Fluorescence) Resonant Energy Transfer (FRET)**

**Advantages**:
- Enhances Stokes shift and reduces reabsorption
- Keeps guest units apart (avoids aggregation) with strong absorption from the host
- Nonradiative dipole-dipole interaction, active within Förster radius $R_0 \sim$ a few nm
- Requires dipole-allowed transitions (S-S or T-T)
- Emission spectrum of host (donor) must overlap absorption spectrum of guest (acceptor)

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Ex: Alq$_3$(host):DCM (guest)
What is a good organic light-emitting material?

...For luminescence?
(owels, microscopy labels)

- Good luminescence quantum yield

→ A « good emitter » for luminescence is not necessarily suitable for lasing

Ex: no demonstration of lasing (to date) in phosphorescent complexes (PLQY ~ 100%)

...For LASERS?

GAIN > LOSSES requires:

- Low ground-state reabsorption = large Stokes shift

- Low $S_1 - S_2$ excited state absorption
- Low $T_1 - T_2$ excited-state absorption
- Good quantum yield of fluorescence (easier to achieve population inversion)
Optical resonators
Resonators based on bulk rods


© Light beam industries

- Diffraction-limited output
- High efficiencies (→ 90%) and high energies (→ mJ) attainable
- Higher thresholds

**Bulk** polymer blocks or sol-gels (size : cm) : need optical polishing before use
Thin-film devices, inspired from inorganic semiconductor laser structures

Organic counterparts

Distributed Feedback waveguide lasers (DFB/DBR)

Microcavities/ Vertical Cavity Surface-Emitting Lasers (VCSELs)

Microrings/microdisks

- Low-loss resonators = Low thresholds
- Thin-film technology:
  - simple deposition and patterning;
  - suitable for organic semiconductors
- Modest optical conversion efficiency (typ. a few %)
- Low output energies (nJ)
Distributed Feedback resonators

Bragg condition:

\[ \frac{m \lambda_{Bragg}}{2} = n_{eff} \Lambda \]
Distributed Feedback resonators

DFB lasers can be transposed in 2D (photonic crystals)


DFB lasers enable the lowest laser thresholds reported to date: down to ~ 50 W/cm²
Other types of microresonators
Random lasing

Application for tumor detection:

External cavities with thin films: the Vertical External Cavity Surface-emitting Organic Laser

**Vertical External Cavity Surface-emitting Organic Laser**

Main features provided by the external resonator:

- Optimal beam quality: TEM\textsubscript{00} beam (diffraction-limited)
- High conversion efficiency when spatial overlap of pump and cavity modes
- Power scaling without increased photodegradation (↗pump beam diameter with constant fluence)
- Long cavities possible (cm) → allows insertion of intracavity elements: frequency doubling, easy tuning, spectral or spatial filtering
Advantage #1 of external cavities: mode matching

✓ Beam quality

Higher-order transverse mode obtained upon a slight misalignment of the cavity:

\[ w(z) = w_0 \sqrt{1 + \left( \frac{M^2 \lambda z}{\pi w_0^2} \right)^2} \]

\[ M^2 = 1.01 \]
High efficiency

- Rhodamine 640 (1%): PMMA
- Output coupler: Reflectivity 95%
- Cavity length: 0.5 mm
- Pump laser: 25 ns FWHM, 10 Hz

Conversion efficiency: 61.5%
Slope efficiency: 71%
Quantum slope efficiency: 82%
Advantage #2 of external cavities: we can put things inside

- A Fabry-Perot etalon for fine tuning over the whole gain spectrum of the dye

**Output coupler**

**Dichroic mirror**

Glass plate coated with dye-doped PMMA @ Brewster angle

Fabry-Perot etalon (free-standing 2-μm-thick PMMA membrane)

Spectrum of a standard VECSOL:
A Fabry-Perot etalon for fine tuning over the whole gain spectrum of the dye

O. Mhibik et al., Appl. Phys. Lett. 102, 041112 (2013)

→ Using 5 easily interchangeable gain chips, continuous tuning over 240 nm

(Coumarin 540A)

Pumping @355 nm, 20 ns
M² = 1 ;
efficiency : 4–7%
Advantage #2 of external cavities: we can put things inside

- a nonlinear frequency-doubling crystal to obtain tunable UV laser light
  - UV (< 360 nm) is practically unreachable directly with OSSLs
  - Tunable UV sources are highly wanted for biophotonic applications
  - VECSOLs offer high intracavity intensities (> MW/cm²)
A UV organic laser (tunable 309-322 nm)

- 1 µJ @ 315 nm
- Conversion efficiency (UV/green pump) = 2%

S. Forget et al., Appl. Phys. Lett. 98 (13), 131102(2011)
The pump
The quest for the “organic laser diode”

Typical organic laser threshold under optical pumping $\sim kW/cm^2$ ($\sim \mu J/cm^2$)

$\rightarrow$ corresponding singlet surface density $n_s^{\text{threshold}} \sim 10^{21} \text{s}^{-1} \text{cm}^{-2}$

$\rightarrow$ assume an OLED with 100% recombination efficiency, $\chi = 0.25$ singlet formed per injected carrier pair, current threshold density would be:

$$j_{\text{threshold}} \sim \frac{n_s^{\text{threshold}}e}{\chi} \sim 1 \text{kA/cm}^2$$

It’s tough, but...
- Peak current densities $> 10 \text{kA/cm}^2$ demonstrated in OSC thin films (CuPc)
- Organic transistors can sustain current densities $> \text{kA/cm}^2$
- In low-loss DFB resonators estimated threshold $< 100 \text{A/cm}^2$

Then... it should work !?
Electrical current brings extra losses

- 1st issue: **electrodes** absorb light/quench excitons

  Low index contrast  
  → Low confinement  
  → Guided mode spreads to the electrodes

- 2\textsuperscript{nd} issue: intense and broad absorption bands of **charge carriers (polarons)** in the spectral gain region: Polaron Absorption / Singlet-Polaron Quenching

  *Recent measurements of polaron absorption cross sections report weak values* $\sim 10^{-17}$-$10^{-18}$ cm$^2$  
  *Rabe et al., PRL 102(13), 137401 (2009)*  
  *Montilla et al., Chem. Phys. Lett. 585 (2013) 133-137*
Electrical current brings extra losses

Electrode and polaron issues are related to low carrier mobilities
Possible solutions: Light-emitting Field-effect transistor, organic crystals?

Electrical current brings extra losses

• 3rd issue: Intense and broad absorption bands of triplet excitons in spectral gain region: Triplet Absorption / Triplet-Singlet Annihilation

Optical pumping

100% singlet excitons
ISC (ns–100 ns) → triplets

Electrical pumping

25% singlets $\tau_s \sim$ ns
75% triplets $\tau_T \sim$ ms – s

Due to lifetime difference, triplets outnumber singlets in CW regime by more than a factor of 3

Triplet engineering needed!
→ Electrical pumping is a big challenge
New avenues for optical pumping

Shrinking Polymer Laser systems

1995 Regenerative amplifier (Tessler) → ~2000 Q-switched Nd:YAG

2008 LED pumped → 2006 Diode pumped → 2003 Microchip laser

Taken from G.Turnbull, OREA Summer School 2012
Laser diode pumping

Blue laser diodes can emit up to \(~1.6\) Watts CW nanoseconds pulsing leads to \(~10\) Watts peak power

LED pumping

- InGaN LEDs commercially available at a few € with CW power ~ Watt over 1 mm² (~ $10^7$ cd/m²), long lifetime

- Decoupling of charge transport/laser emission: « indirect electrical pumping »

- Requires low-loss resonators, LEDs are incoherent and then hard to focus

BBEHP-PPV with mixed order DFB gratings:

Threshold ~200 W/cm² (LED pumping)
Novel concepts
Organic plasmonics

Huge organic gain can help compensating huge losses of metals in plasmonic circuitry

De Leon et al., Nature Photonics 4(6), 382 (2010)
Organic plasmonics: a surface plasmon nanolaser or “spaser”

Minimum size for a classical photon laser \( V \sim \left( \frac{\lambda}{2} \right)^3 \)

Gain = organic dye (OG488) in SiO\(_2\)
Feedback = Gold nanoparticle acting like a nanoresonator for SPs
Diameter = 44 nm
Beyond photon lasers: polariton lasers

Room-temperature polariton lasing in an organic single-crystal microcavity

S. Kéna-Cohen and S. R. Forrest

Nature Photonics
Published Online: 18 April 2010 | DOI: 10.1038/NPHOTON.2010.86
Lasers with living biological cells

LETTERS
PUBLISHED ONLINE: 12 JUNE 2011 | DOI: 10.1038/NPHOTON.2011.99

Malte C. Gather¹,² and Seok Hyun Yun¹,²,³,⁴*

a
b

Absorption
Spontaneous emission
Stimulated emission

-3 ns

Dichroic mirror
Pump
Lens
Cavity mirrors
GFP solution

Cavity mirrors

a
b

Pump energy (nJ)

Output energy (a.u.)

0
0
10
20
30

-3 ns

Emission/absorption (norm.)

440
460
480
500
520
540
560
580

Wavelength (nm)

a
b

Emission/absorption (norm.)

Abs
PL

500
520
540
560
580

Wavelength (nm)

100
10
1

Threshold energy (nJ)

eGFP concentration (µM)
Conclusion

✓ OSSLs are promising devices for low cost, compact, and broadly tunable coherent sources in the visible spectrum: spectroscopy, sensing

✓ Two major scientific challenges:
  - Continuous-Wave operation
  - Electrical pumping!

✓ Materials are the key: engineering of triplet states

✓ «indirect» electrical pumping by low cost and efficient inorganic devices (laser diodes and LEDs) open the way for applications

✓ Flexibility of organic gain media makes them ideal players to test innovative concepts: organic plasmonics, exotic types of lasing (polariton, biolaser...)

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Further reading

Review papers on organic lasers:


Our book (sept. 2013):