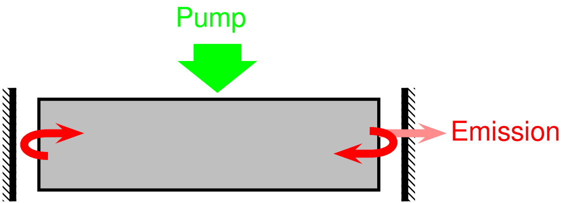
Active control of random lasers

Nicolas Bachelard, Institut Langevin (Paris),
Supervisor Patrick Sebbah

Introduction: Random Laser?

Classical Laser



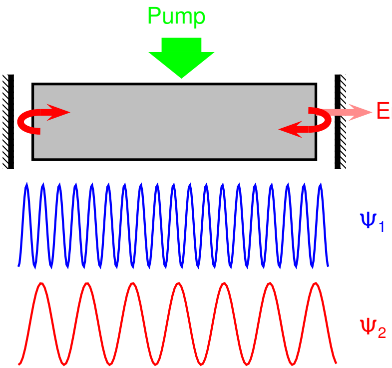
Components

- Gain medium
- Optical cavity
- Feedback = Mirrors

Properties

- Regular spectrum
- Directional emission
- Amplification fixed by cavity

Classical laser:



$\Rightarrow$ Maxwell-Bloch along passive modes (Ω_k, Ψ_k):

$\Rightarrow$ Lasing modes solution of

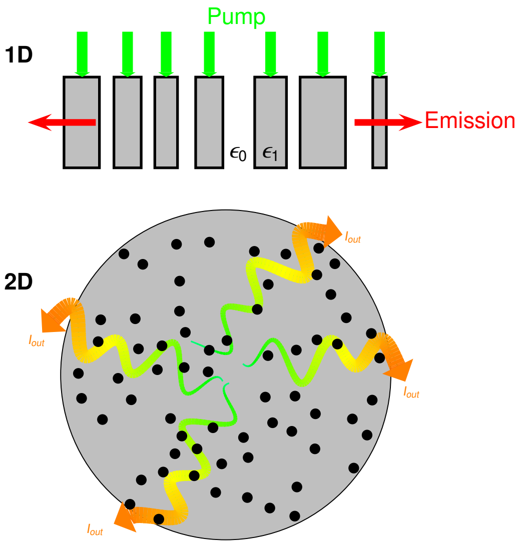
no coupling

$$\omega^2 = \begin{pmatrix} \Omega_1^2 & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & \Omega_n^2 \end{pmatrix} + \begin{pmatrix} V_{11} & \dots & \textcircled{0} \\ \vdots & \ddots & \vdots \\ 0 & \dots & V_{nn} \end{pmatrix} + \cancel{\epsilon_{NL}}(E)$$

$\Rightarrow$ Non linearities ≈ 0 (near threshold)

Lasing Modes $\approx$ passive ✚ No coupling

Random Laser



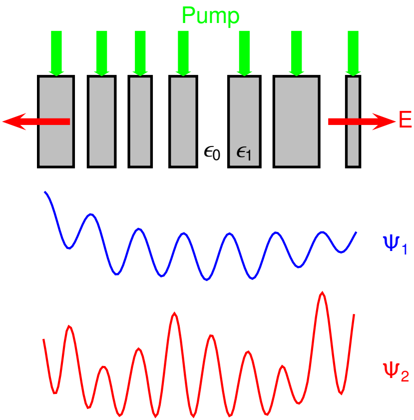
Components

- Gain medium
- Scatterers
- Feedback = Scattering

Properties

- Random spectrum
- Random emission
- Gain unconstrained

Random laser:



$\Rightarrow$ Local gain $f_e(x)$

$\Rightarrow$ Maxwell-Bloch along passive modes (Ω_k, Ψ_k)

coupling

$$\omega^2 = \begin{pmatrix} \Omega_1^2 & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & \Omega_n^2 \end{pmatrix} + \begin{pmatrix} V_{11} & \dots & V_{1n} \\ \vdots & \ddots & \vdots \\ V_{n1} & \dots & V_{nn} \end{pmatrix} + \epsilon_{NL}(E)$$

$\Rightarrow$ Non linearities ≈ 0 (near threshold)

Lasing Modes $\neq$ passive + Coupling available

Condition of mode coupling:

- Coupling term:

Passive system — Local gain

$$V_{pq} = \int \Psi_p(x)\Psi_q(x) f_e(x) dx$$

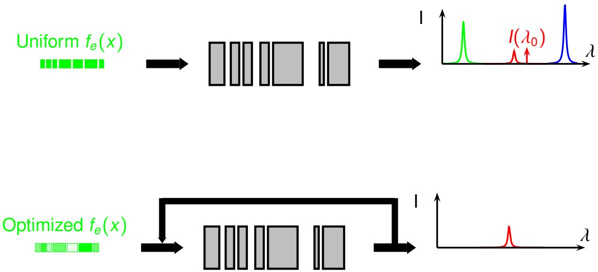
$\Rightarrow \Psi_p \Psi_q \neq 0$ if modes overlap

$\Rightarrow$ Non uniform gain influences mode coupling

$\Rightarrow$ Question: Gain = degree of freedom?

Control of random laser with non-uniform pump profile

Method



Idea

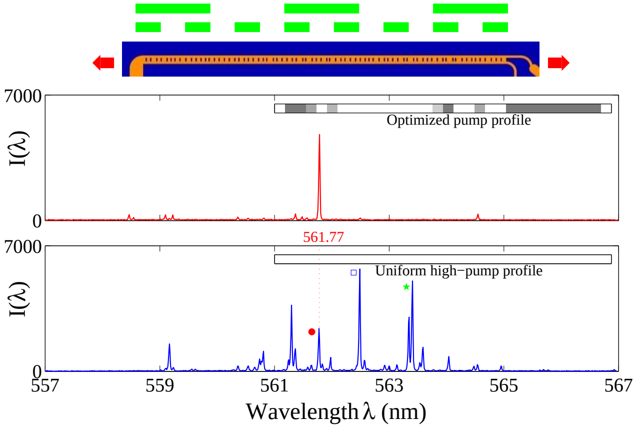
- Input = Pump Profile $f_e(x)$
- Output = Spectrum

Control

- $f_e(x) \rightarrow$ SLM
- Criterion = $\frac{I(\lambda_0)}{max(I(\lambda_{i \neq 0}))}$
- Optimization Algorithm

N. Bachelard, J. Andreasen, S. Gigan and P. Sebbah (PRL), 2012

Spectral optimization



Sample

- 1D microfluidic
  → Dielectric = PDMS
  → Gain = Rhodamine 6G
- Hadamard basis 32 elements

Optimization

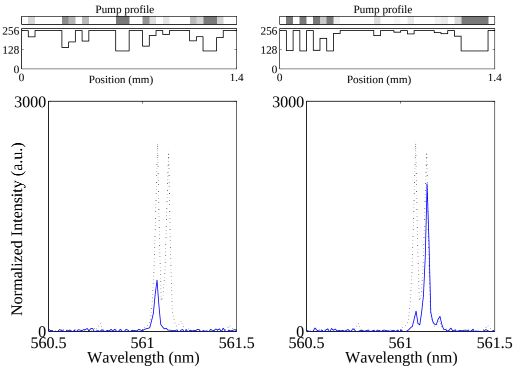
- Spectrum acquisition
- ≈ 250 iterations
- ≥ 10 dB sideband rejection

N. Bachelard, S. Gigan, X. Noblin and P. Sebbah (Nat. Phy.), 2014

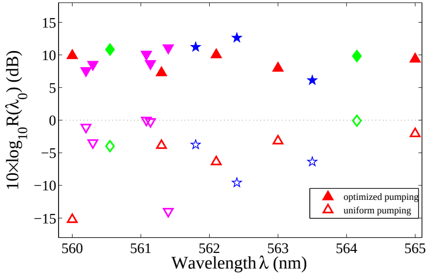
B. N. Shivakiran Bhaktha, N. Bachelard, X. Noblin and P. Sebbah (APL), 2012

Performances

- Spectral Selectivity down to 0.06 nm



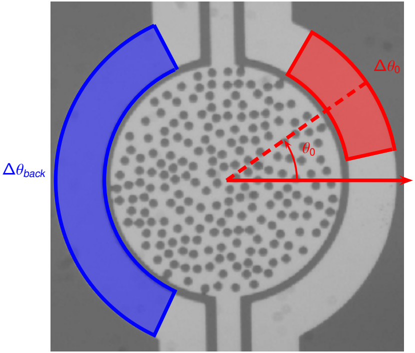
- Single-mode over the whole dye Bandwidth



N. Bachelard, S. Gigan, X. Noblin and P. Sebbah (Nat. Phy.), 2014

Control the emission directivity of 2D random lasers

Method



Sample

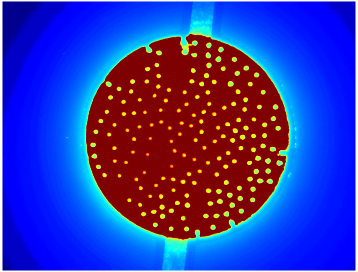
- 2D microfluidic
  → Dielectric = resin
  → Gain = Rhodamine 6G
- Zernike basis 100 elements

Optimization

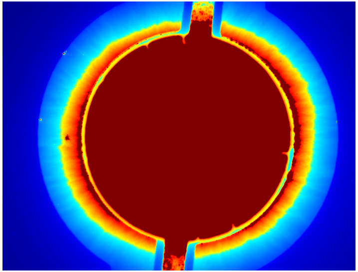
- CCD acquisition
- Criterion $= \frac{I_{\Delta\theta_0}}{I_{2\pi}} - \frac{I_{2\pi}}{I_{\Delta\theta_{back}}}$
- 200 iterations

Uniform pumping

- Below threshold

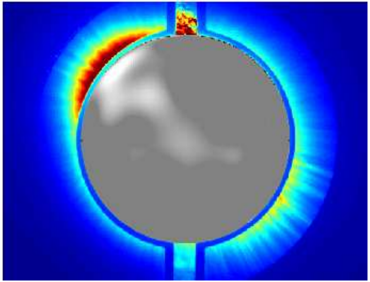


- Above threshold

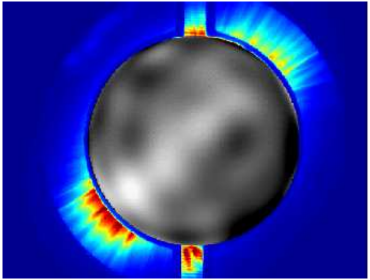


Optimized pumping

- $\theta_0 = 135^\circ$ and $\Delta\theta_0 = 45^\circ$



- $\theta_0 = -135^\circ$ and $\Delta\theta_0 = 45^\circ$



Conclusion

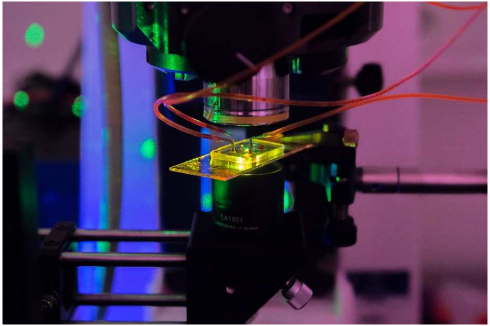
Conclusion:

Achievements:

- Control of spectral emission
- Control of emission directivity

Perspectives:

- Temporal control
- Different lasers
- Non-hermitian problems



Thank you for your attention!!!