Random Lasers

Paul Chiang
Outline

• Laser Overview
• Conventional and Random
• Why Random Lasers?
• Category of Random Lasers
• Boosted Random Lasers
• Conclusion
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Laser Overview

History

Theory | 1917
Albert Einstein
Stimulated Emission

First Laser | 1960
Theodore Maiman
Hughes Research Lab

Photonic Bomb | 1968
Vladilen Letokhov
Strong Scattering

Ref. [1]
Laser Overview Components

**INPUT SOURCE**
- Electrical
- Optical

**FEEDBACK**
- High reflector
- Minimized scattering

**GAIN MEDIUM**
- Gas: CO$_2$
- Solid: Ruby, Nd:YAG Sapphire
- Liquid: Fluorescent dye
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Conventional and Random

- Total reflection
- $L = \text{multiple} \times \lambda/2$

- No confinement
- Multiple scattering
- Gain path length > loss $\rightarrow$ lasing

Ref. [2]
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Why Random Lasers?

- Speed of transistor become saturated

Ref. [3]
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Category of Random Lasers

Incoherent Feedback

**LETTERS TO NATURE**

*Laser action in strongly scattering media*

N. M. Lewandy, R. M. Balachandran, A. S. L. Gomes & E. Sauvain

- 3 mJ pump
- w/o scatters

- 3 mJ pump with scatters
- Amplitude / 20

FIG. 1. a, Emission spectrum of a $2.5 \times 10^{-5}$ M solution of rhodamine 640 perchlorate in methanol pumped by 3-mJ (7-ns) pulses at 532 nm. b and c, Emission spectrum of the TiO$_2$ nanoparticle ($2.8 \times 10^{14}$ cm$^{-3}$) colloidal dye solution pumped by 2.2-mJ and 3-mJ (7-ns) pulses, respectively. The amplitude of the spectrum in b has been scaled up by a factor of 10, whereas that in c has been scaled down by a factor of 20.
Category of Random Lasers  Incoherent Feedback

LETTERS TO NATURE

Laser action in strongly scattering media
N. M. Lewandy, R. M. Balachandran, A. S. L. Gomes & E. Sauvain

Ref. [4]
**Category of Random Lasers**  
Coherent Feedback

**Random Laser Action in Semiconductor Powder**

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**Figure 3.** Top view (a) and lift view (b) scanning electron micrographs of ZnO nanorods grown on a sapphire substrate. (c) Emission spectra of the ZnO nanorods when the incident pump power is (bottom to top) 3.2, 4.3, 6.1, 7.0 and 11.1 μJ/cm².

**Figure 4.** (a) Scanning electron micrograph of a microcluster of ZnO nanocrystals. (b) Optical image of the emitted light distribution across the cluster. The incident pump pulse energy is 2.1 ηJ. (c) Spectrally integrated emission intensity as a function of the incident pump pulse energy. (d) Spectrum of emission from the cluster at the incident pump pulse energy of 6.35 ηJ.

**Line width 0.2 nm**

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Ref. [5],[12]-[16]
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Boosted Random Laser

**PLASMONICS**  (Resonance)

- Reduced threshold
- Enhanced signals
- Tunable wavelength
- Mode interactions

**HYPERBOLIC MATEMATERIALS**  (Non-resonance)

- Reduced threshold
- Broadband enhanced signals
- Increased possibility of forming closed loop
Boosted Random Laser Plasmonics

Controlling Random Lasing with Three-Dimensional Plasmonic Nanorod Metamaterials
Zhuoxian Wang,1 Xiangeng Meng,1,2 Seung Ho Choi,1 Sebastian Knitter,5 Young L. Kim,1 Hui Cao,5 Vladimir M. Shalaev,1 and Alexandra Boltasseva1,6

- Tilted silver nanorod

Reduced threshold by increasing silver nanorod length due to strong scattering

Ref. [6]
Boosted Random Laser Plasmonics

- Tunable wavelength by gold nanoparticles
  - Annealing temp.
  - Concentration of gold colloidal solution
Boosted Random Laser Plasmonics

- Pump threshold vs shell thickness

Ref. [8]
Robust enhancement of random laser action assisted by hyperbolic metamaterials

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Abstract: We use hyperbolic metamaterials to strongly enhance random laser action and reduce the lasing threshold. The excited high-\(k\) modes can increase the possibility of forming closed loop paths and decrease the energy consumption of photon propagation.

OCIS codes: (140.3460) Lasers; (166.3918) Metamaterials; (230.4170) Multilayers

\[ \frac{k_x^2 + k_y^2}{\varepsilon_\parallel} - \frac{k_z^2}{|\varepsilon_\perp|} = \left( \frac{\omega}{c} \right)^2 \]

Ref. [9],[10]
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Conclusion

ADVANTAGE

- Low cost
- Sample-specific wavelength of operation
- Small size
- Flexible shape
- CMOS compatibility

APPLICATION

- Imaging
- Medical diagnostics
- Display
- Miniature light source in photonic integrated circuit

Ref. [11]
Q & A
References

Slides

Theory
Anderson localized modes
Lucky photons on long path
Pre-localized modes
Delocalized, interacting modes
Several of these scenarios
Hyperbolic Metamaterials

\[ \frac{k_x^2 + k_y^2 + k_z^2}{\varepsilon} = \left( \frac{\omega}{c} \right)^2 \]

\[ - \frac{k_x^2 + k_y^2}{|\varepsilon_\parallel|} + \frac{k_z^2}{|\varepsilon_\perp|} = \left( \frac{\omega}{c} \right)^2 \]

\[ \frac{k_x^2 + k_y^2}{\varepsilon_\parallel} - \frac{k_z^2}{|\varepsilon_\perp|} = \left( \frac{\omega}{c} \right)^2 \]

Ref. [9]