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: CO₂
- 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 → lasing

Ref. [2]
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Why Random Lasers?

- Speed of transistor become saturated
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Category of Random Lasers  Incoherent Feedback

LETTERS TO NATURE

Laser action in strongly scattering media
N. M. Lawandy, 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 $2.5 \times 10^{-3}$ 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 ($2.8 \times 10^{16}$ 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. Lawandy, R. M. Balachandran, A. S. L. Gomes & E. Sauvalin

Ref. [4]
Category of Random Lasers  Coherent Feedback

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

Zhenxian Wang,1 Xiangeng Meng,2,3 Seung Ho Choi,2 Sebastian Knitter,1 Young L. Kim,1 Hui Cao,1 Vladimir M. Shalaev,1 and Alexandra Boltasseva1,4

- Tilted silver nanorod

- Reduced threshold by increasing silver nanorod length due to strong scattering
Boosted Random Laser Plasmonics

- Tunable wavelength by gold nanoparticles
  - Annealing temp.
  - Concentration of gold colloidal solution

Ref. [7]
Boosted Random Laser Plasmonics

Metal–Dielectric Core–Shell Nanoparticles: Advanced Plasmonic Architectures Towards Multiple Control of Random Lasers

Xiangeng Meng,* Koji Fujita,* Yusuke Moriguchi, Yanhua Zong, and Katsuhiro Tanaka

- Pump threshold vs shell thickness

Ref. [8]

Mode interactions

Gold only

Gold + Silica
Boosted Random Laser **Hyperbolic Metamaterials**

Robust enhancement of random laser action assisted by hyperbolic metamaterials

Hung-I Lin$^{1,2}$, Yu-Ming Liao$^{3}$, Kun-Ching Shen$^{1}$, and Yang-Fang Chen$^{1,2,*}$

$^1$Graduate Institute of Applied Physics, National Taiwan University, Taipei 106, Taiwan
$^2$Department of Physics, National Taiwan University, Taipei 106, Taiwan
$^3$Research Center for Applied Sciences, Academia Sinica, Taipei 115, Taiwan

Abstract: We use hyperbolic metamaterials to strongly enhance random laser action and reduce 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; (160.3918) Metamaterials; (230.4170) Multilayers

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

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

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

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