Suppressing spatiotemporal lasing instabilities with wave-chaotic microcavities

Juman Kim 2018/11/01

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Introduction of the author

- Name: Hui Cao
- CV:

-thesis:

B.D Quantum optics(Peking, with her father)

PhD: semiconductor cavity QED(Stanford, Yoshihisa Yamamoto)

Professor @ Yale University(Now)

-Work

Opened new field of ‘Random laser’

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- Where comes the lasing instability?
- Conventional way to decrease instabilities
- Conventional laser and experimental setup
- Complex multiwave interference can work for it
  - D-shaped cavity (experiment)
  - 1D dielectric slab with random fluctuation of refractive index (theory)
- Conclusion

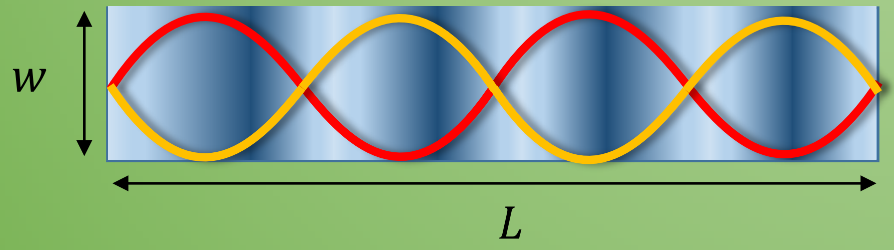
1. Where comes the lasing instabilities?

- Kerr effect: $n(\vec{r},t) = n_0 + n_2 I(\vec{r},t) + \cdots$

- Spatial hole burning: Non-uniform gain medium originated from Competition between different lasing modes

- Filamentation: wave guiding by self-focusing and self-defocusing

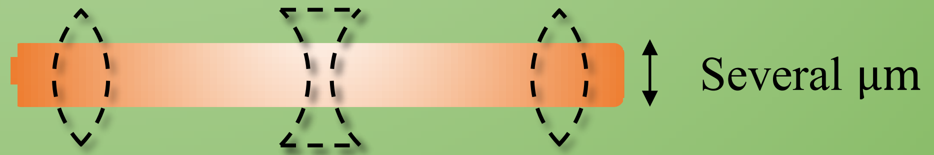
Spatial hole burning



W : 60 μm
L : 1 mm ($\gg W$)

<FP laser>

Filamentation



<Schematics>

2. Previous way to decrease instabilities

- By using the PT symmetry, succeeded in reducing the number of lasing mode.

OPTICS

Parity-time–symmetric microring lasers

Hossein Hodaei, Mohammad-Ali Miri, Matthias Heinrich,* Demetrios N. Christodoulides, Mercedeh Khajavikhan†

The ability to control the modes oscillating within a laser resonator is of fundamental importance. In general, the presence of competing modes can be detrimental to beam quality and spectral purity, thus leading to spatial as well as temporal fluctuations in the emitted radiation. We show that by harnessing notions from parity-time (PT) symmetry, stable single–longitudinal mode operation can be readily achieved in a system of coupled microring lasers. The selective breaking of PT symmetry can be used to systematically enhance the maximum attainable output power in the desired mode. This versatile concept is inherently self-adapting and facilitates mode selectivity over a broad bandwidth without the need for other additional intricate components. Our experimental findings provide the possibility to develop synthetic optical devices and structures with enhanced functionality.

Since the early days of the laser, enforcing single-mode operation in a given arrangement has been one of the primary goals of cavity design (*1*). At first glance, one might expect these challenges to become less acute in the course of miniaturization, as the separation of resonances, or free spectral range, scales inversely with size. However, despite their smaller size, mode management in semiconductor lasers is still demanding because of their large inhomogeneously broadened gain bandwidth (*2*). In such broadband gain environments, the lasing of the desired mode does not prevent the neighboring resonances from also experiencing amplification. Consequently, additional steps must be taken to suppress the competing parasitic modes. This can be accomplished in a number of ways, as, for example, coupling to detuned external cavities (*3*), by including intracavity dispersive elements such as distributed feedback gratings or distributed Bragg mirrors (*4*–*6*), by spatially modulating the pump (*7*), or more recently by extreme confinement of light in subwavelength structures using metallic cavities (*8*–*10*). However, not all of these schemes are practically compatible with every type of resonator, and each of them introduces further demands in terms of design complexity and fabrication tolerances. Clearly, of importance will be to identify alternative strategies through which mode selection can be established not only in a versatile manner, but also without any negative impact on the overall efficiency.

A prominent class of integrated laser arrangements is based on microring resonators (*11*, *12*). By virtue of their high refractive index contrast, such configurations can support whispering gallery modes that exhibit high quality factors and small footprints, thus making them excellent candidates for on-chip integrated photonic applications. However, like many other microscale resonators, these cavities tend to support multiple longitudinal modes with almost similar quality factors throughout their gain bandwidth, while offering little control in terms of mode discrimination with conventional techniques.

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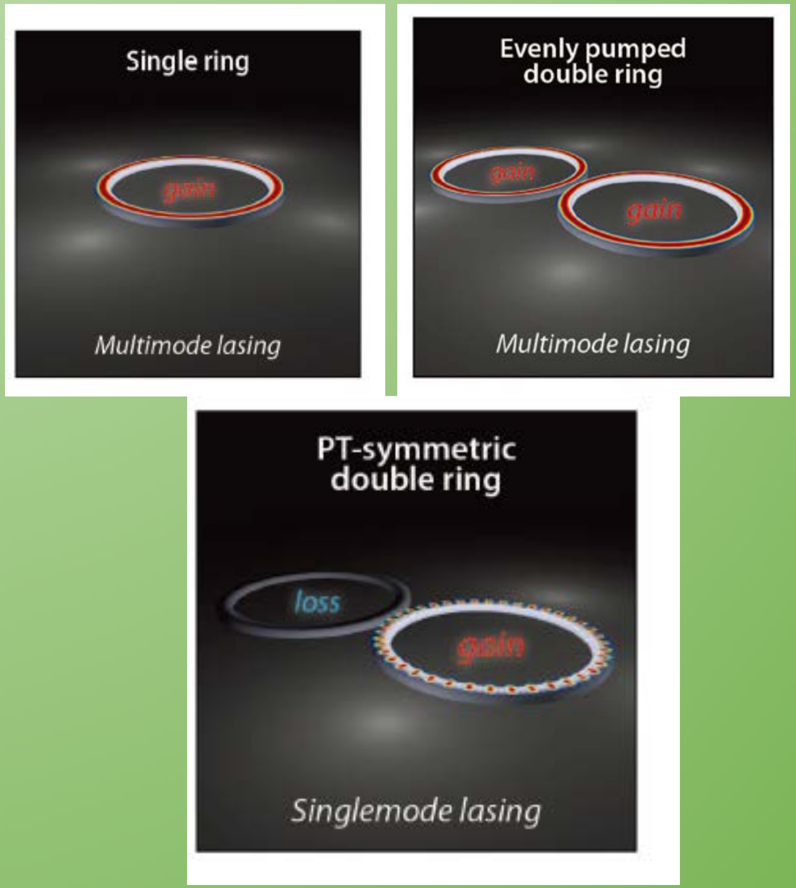
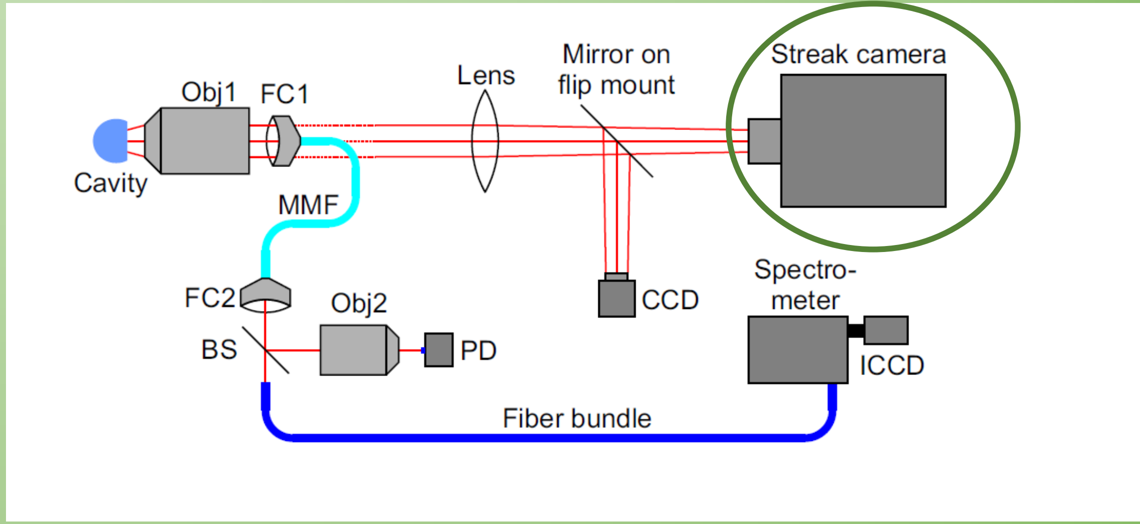
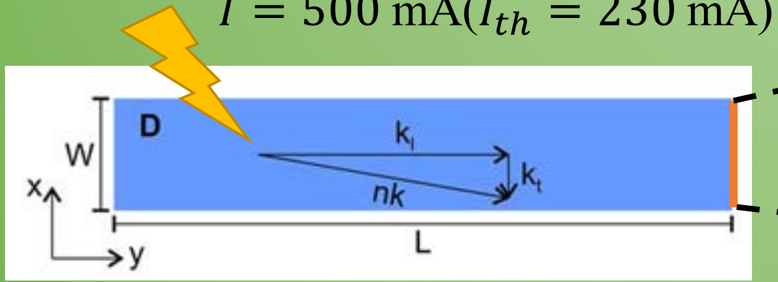


3. Experimental setup and conventional laser

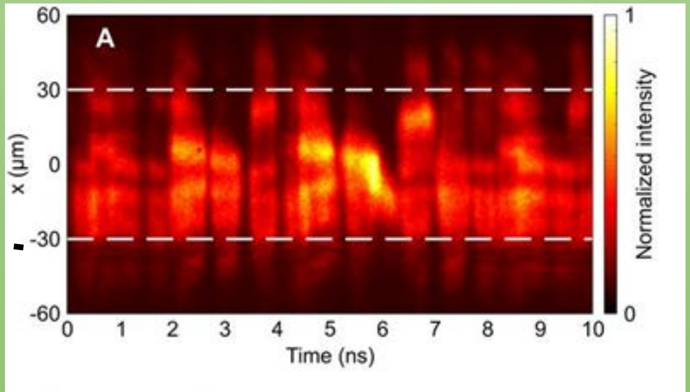


$I = 500\ \mathrm{mA}(I_{th} = 230\ \mathrm{mA})$

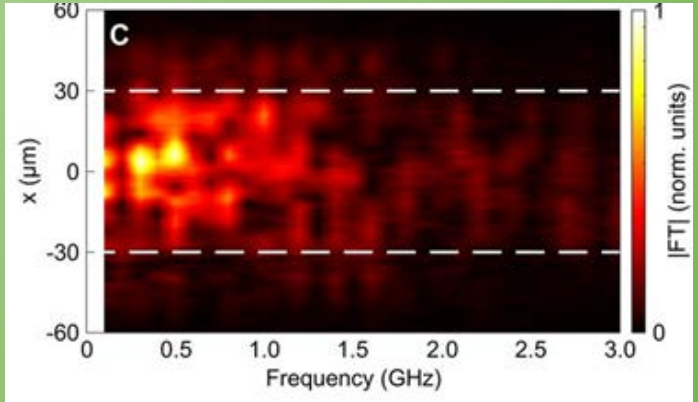


W : 60 μm
L : 1 mm ($\gg W$)

<FP GaAs quantum well Broad-area edge emitting Laser>



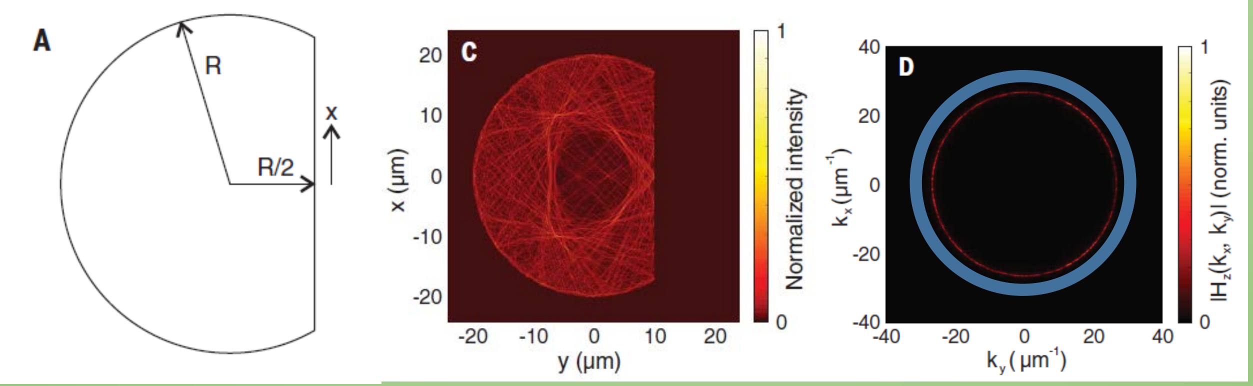
<Spatiotemporal intensity distribution>



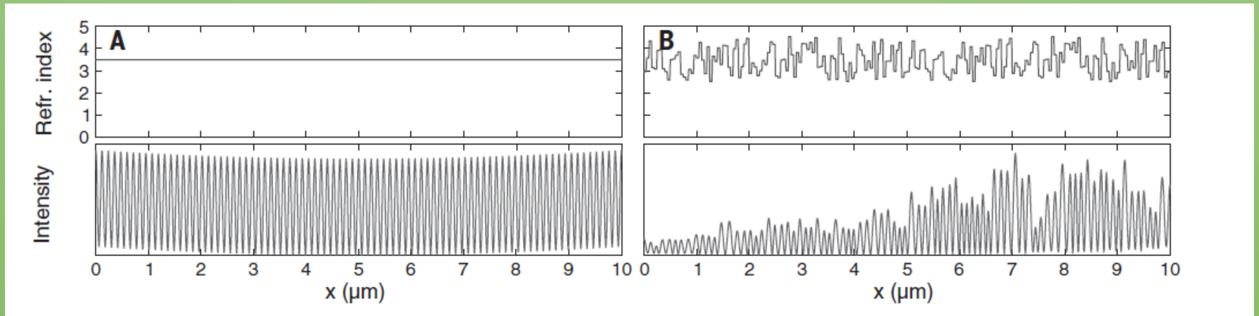
<Temporal Fourier transform>

4. Complex multiwave interference can work for it

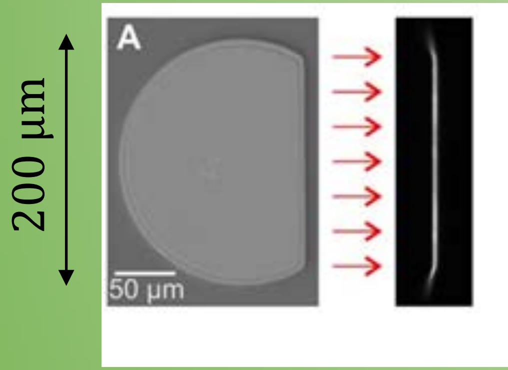
- 1. **D-shaped cavity**: wave-chaotic mode



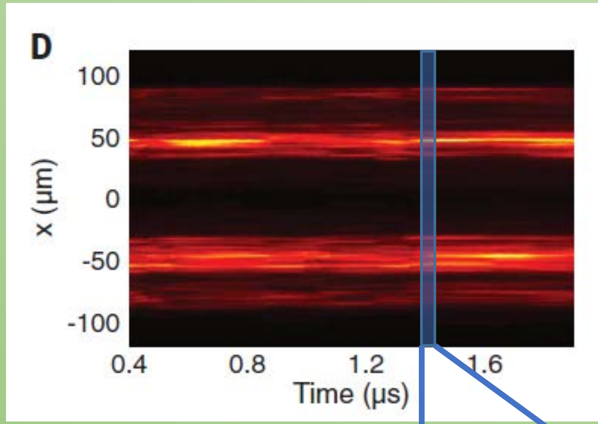
- 2. **1D dielectric slab with random fluctuation of refractive index**: disordered structure



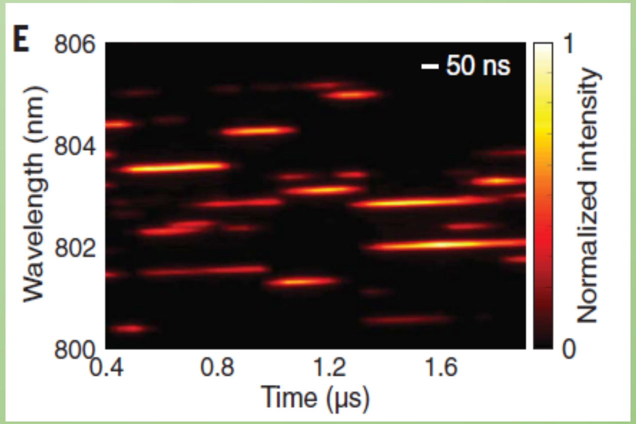
4-1. D-shaped cavity



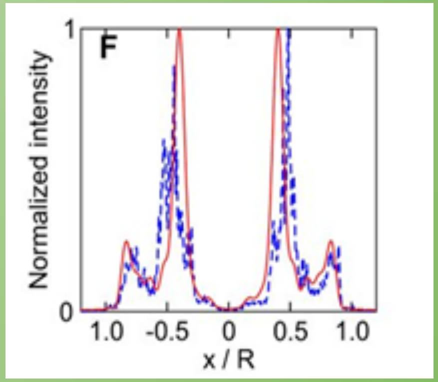
$I_{th} = 150\ \mathrm{mA}$



<spatio-temporal>



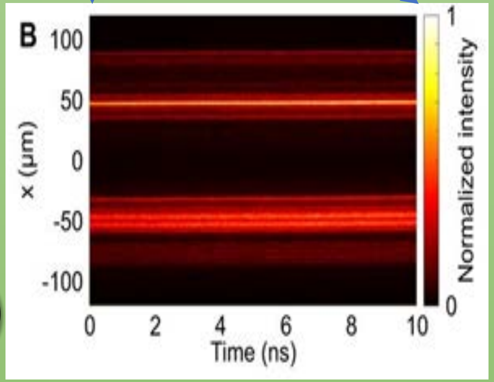
<spectrochronogram>



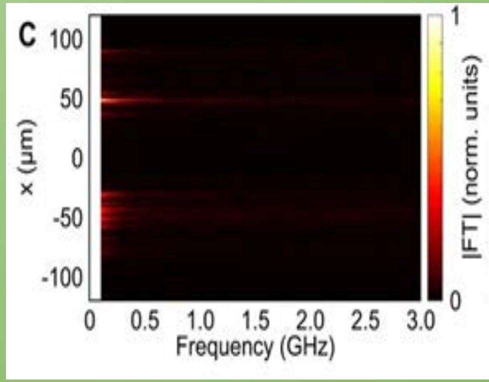
<emission pattern>

$$\tau_{corr}^{(x)}, \tau_{corr}^{(\lambda)} \approx 100\ \mathrm{ns}$$

$$(\tau_{corr} \leq 1\ \mathrm{ns\ for\ stripe})$$



<fine time resolution>

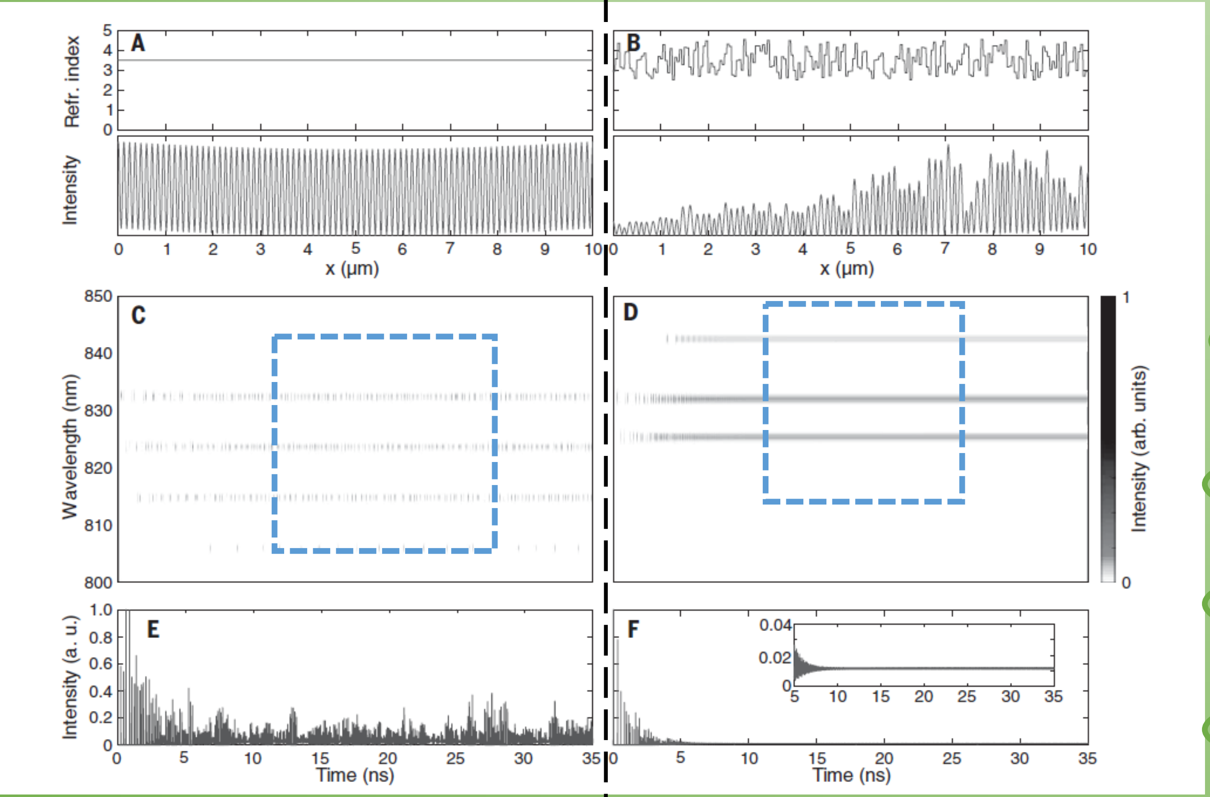


<Temporal Fourier Transform>

4-2. 1D dielectric slab with random fluctuations of refractive index

Homogenous n

Randomly fluctuating n



- Full-wave Model(no rotating wave, no paraxial approximation)

-Solving Maxwell Bloch equation with FDTD method