Spatiotemporal stabilization of PT-symmetric BAS Lasers

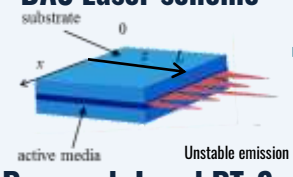
J. Medina[1], M. Botey[1], R. Herrero[1], and K. Staliunas[1,2]
[1]Departament de Física, Universitat Politècnica de Catalunya (UPC), Colom 11, E-08222 Terrassa, Barcelona, Spain
[2]Institució Catalana de Recerca i Estudis Avançats (ICREA), Passeig Lluís Companys 23, E-08010, Barcelona, Spain
judith.medina@upc.edu

Abstract

We propose a feasible and compact scheme to control and stabilize the spatiotemporal dynamics of Broad Area Semiconductor (BAS) lasers applying a local PT-symmetric potential [1] to enhance and localize light into a narrow, stable and bright emitted beam. The laser pump modulation, with a central symmetry axis, induces in-phase gain and refractive index modulations due to the Henry factor, which are spatially dephased to obtain local PT-symmetry by an appropriate modification of the index profile [2]. The optimized performance is found by an exhaustive exploration of the modulation parameters, achieving a significant improvement in terms of intensity enhancement, beam concentration and temporal stability [3]. This approach produces a two-fold benefit: light localization into a narrow beam emission and the control over the spatial and temporal dynamics improving the laser stability [4].

Motivation

BAS Laser scheme



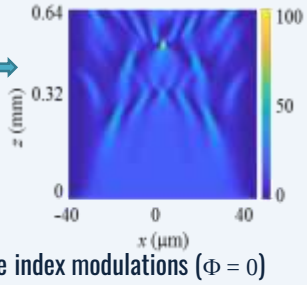
Model

$$\frac{\partial A}{\partial z} = \frac{i}{2k_0 n}\frac{\partial^2 A}{\partial x^2} + s[(1-ih)N - (1+\alpha)]A + i\Delta n(x)k_0$$

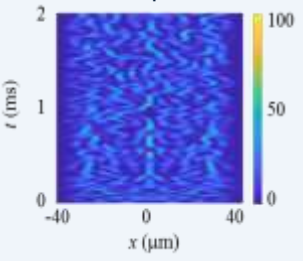
$$\frac{\partial N}{\partial t} = \gamma(-N-(N-1)|A|^2 + p_0 + \Delta p(x) + D\nabla^2 N)$$

Unmodulated BAS numerical integration

Filed distribution within the BAS



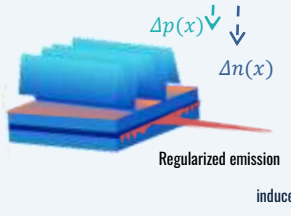
Unstable temporal emission



BAS lasers drawbacks
- spatially inhomogeneous
- temporally unstable
- poor beam quality

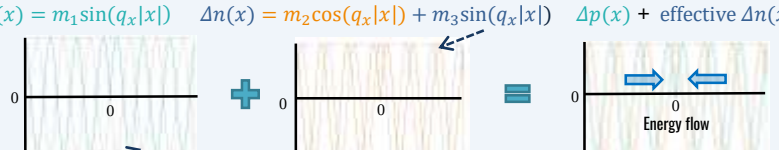
Need for a solution to obtain a
- spatially regularized
- temporally stabilized
- bright emission

Proposal: Local PT-Symmetry



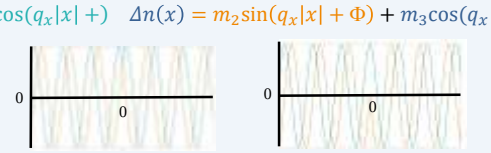
Pump and Refractive index modulations ($\Phi = 0$)

$\Delta p(x) = m_1 \sin(q_x|x|)$ $\quad \Delta n(x) = m_2 \cos(q_x|x|) + m_3 \sin(q_x|x|)$ $\quad \Delta p(x)$ + effective $\Delta n(x)$



General pump and effective refractive index modulations

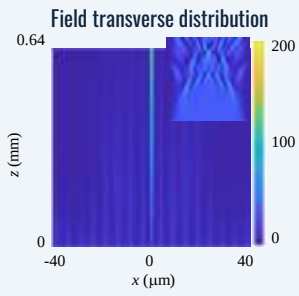
$\Delta p(x) = m_1 \cos(q_x|x| +)$ $\quad \Delta n(x) = m_2 \sin(q_x|x| + \Phi) + m_3 \cos(q_x|x| + \Phi)$



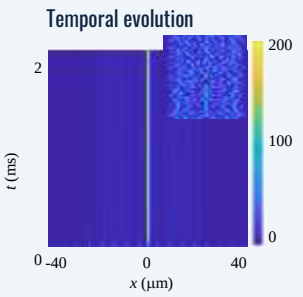
Results

Amplifier

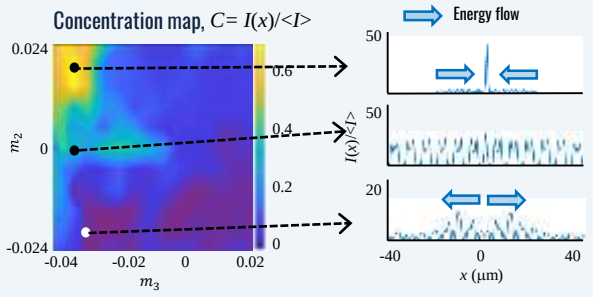
Field transverse distribution



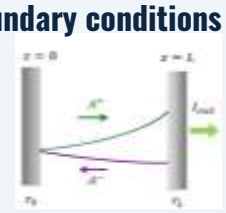
Temporal evolution



Concentration map, $C = I(x)/\langle I \rangle$



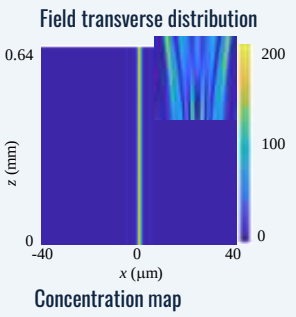
Boundary conditions for the Laser



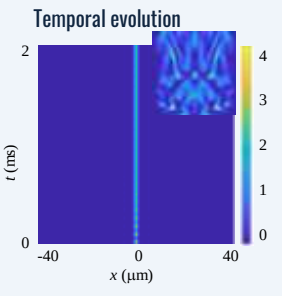
$$A(x,z,t) = A^+(x,z,t)e^{-ik_0 z} + A^-(x,z,t)e^{ik_0 z}$$
$$A^+(x,z=L,t) = r_L A^-(x,z=L,t)$$
$$A^-(x,z=0,t) = r_0 A^+(x,z=0,t)$$

Laser r_0=0.99 ; r_L=0.9

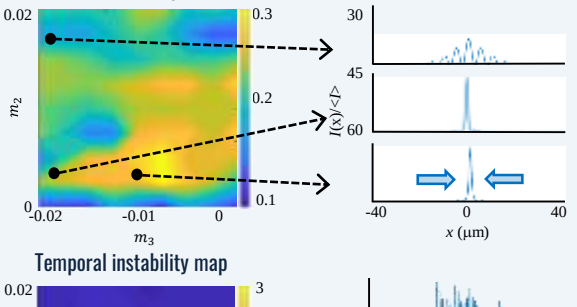
Field transverse distribution



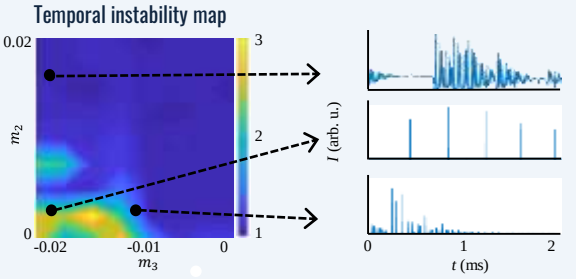
Temporal evolution



Concentration map

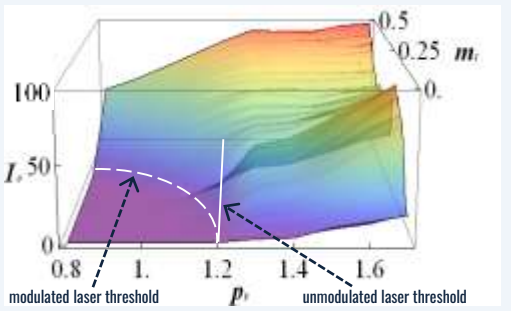


Temporal instability map

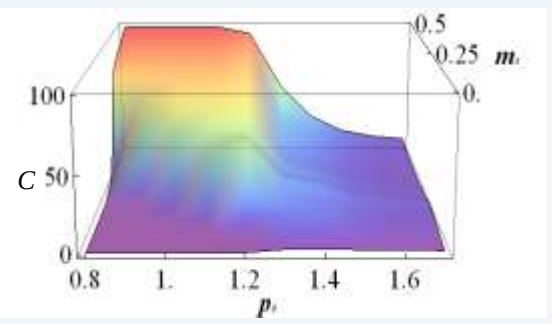


Laser r_0=0.99 ; r_L=0.04

Intensity at the centre



Concentration at the centre



Conclusions

- We impose local PT-symmetric potentials to tailor and control the complex spatial dynamics of BAS amplifiers and lasers by inducing modulations on pump and refractive index.
- The field regularization mechanism relies on the inward light coupling, which directs and concentrates light from each of the two half-spaces ($x < 0$ and $x > 0$) towards the center, with a significant intensity field enhancement and concentration of the emitted beam.
- When the center holds a high refractive index, with two side index maxima ($\Phi = \pi/4$), the local of PT-symmetry potential induces a temporally stable emission in the form of a narrow beam for a wide range of modulation amplitudes, this area of temporal stability partially coincides with the maximum concentration area.
- The system is studied under different working conditions of input power and mirror reflectivity, showing a substantial filed regularization, especially for pumps close to the laser threshold.
- The proposed scheme is general and could be implemented in other semiconductor lasers.

References

[1] W. W. Ahmed, R. Herrero, M. Botey, Z. Hayran, H. Kurt and K. Staliunas, "Directionality fields generated by a local Hilbert transform," Phys. Rev. A 97(3), 033824 (2018).
[2] W. W. Ahmed, R. Herrero, M. Botey and K. Staliunas, "Locally parity-time-symmetric and globally parity-symmetric systems," Phys. Rev. A 94, 053819 (2016).
[3] W. W. Ahmed, J. Medina, R. Herrero, M. Botey, and K. Staliunas," Stabilization of Broad-area semiconductor laser sources by simultaneous index and pump modulations", Opt. Lett. 43,11 (2018).
[4] J. Medina, R. Herrero, M. Botey, and K. Staliunas, "Spatiotemporal Stabilization of Locally PT-symmetric Semiconductor Lasers", http://arxiv.org/abs/1906.09146.