Low-threshold optical bistabilities in ultra-thin plasmonic films

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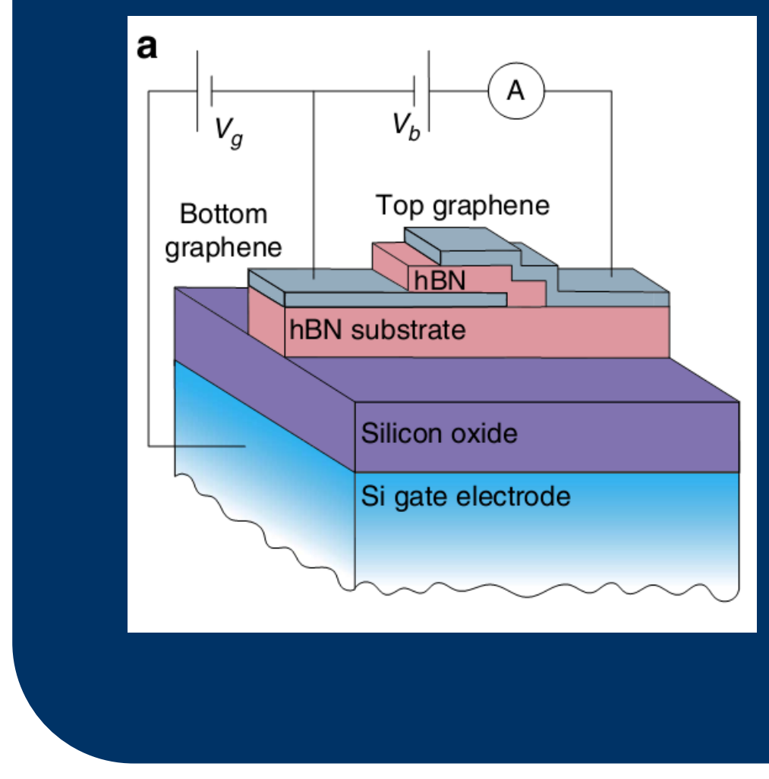
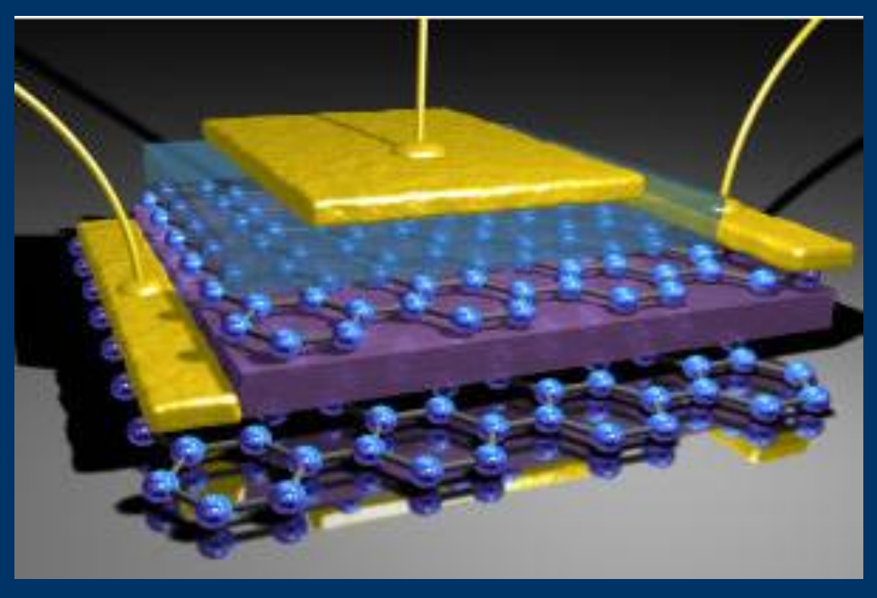
Backgrounds:

Optical bistability can be used as optical switching, optical memories, optical transistors, optical diode, and optical computing.





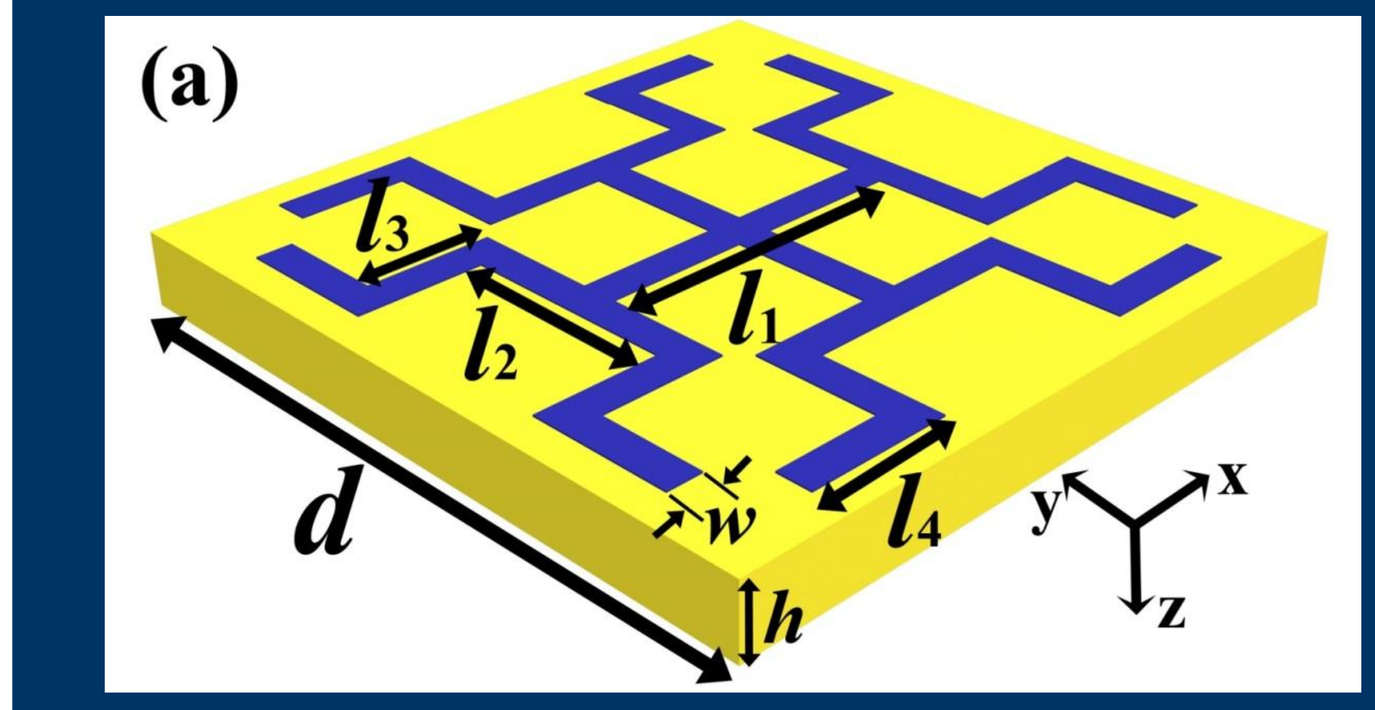
Problem:

- Incident light needs high power
- Devices must be comparable to wavelength to sustain a FP mode

Motivation:

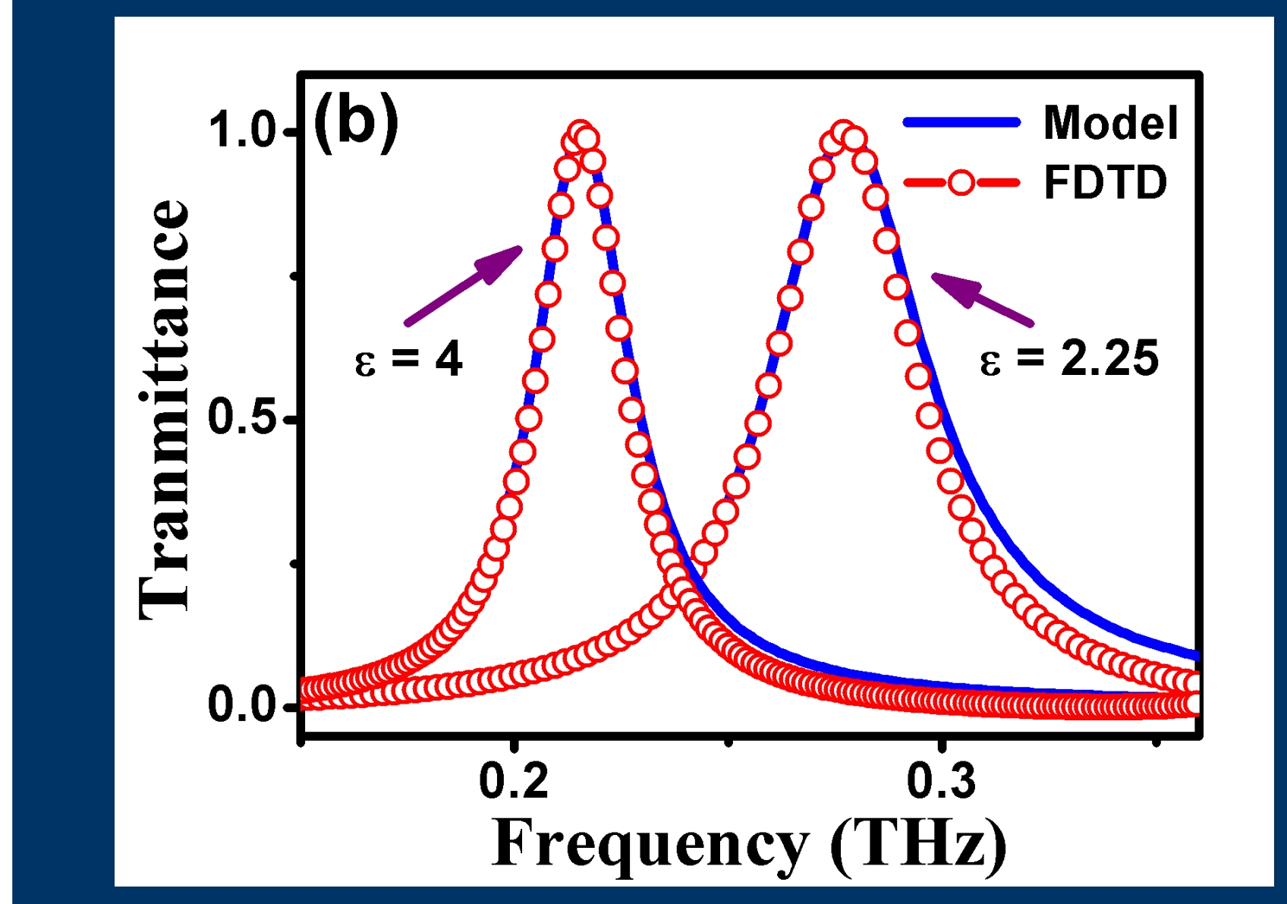
- A new mechanism to achieve OB at low input power
- Device with a miniaturized size

Linear results:



Schematic of the holey metallic plate (HMP) device

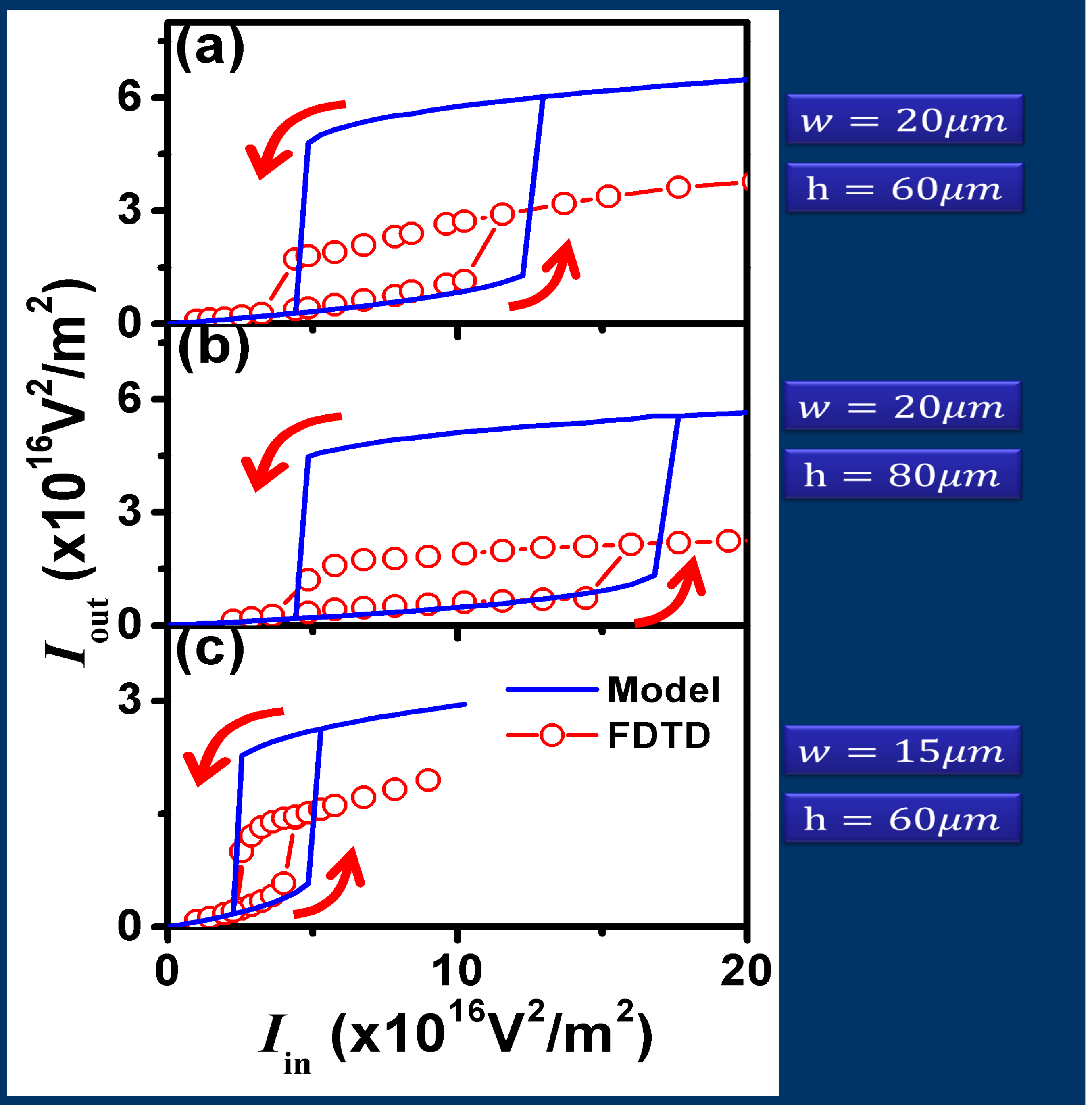
Yellow region: metal
Blue region: Kerr material



Transmission spectra

- ➢ Red shift when dielectric of Kerr material increases
- ➢ FDTD calculation agrees with Model calculation

Nonlinear results:



◆ Thickness is only 1/25 of the wavelength
◆ Threshold *independent* of the film thickness
◆ Saturation increases when *h* increased
◆ Strongly depend on width of the aperture
◆ Difference between FDTD and model because of self-phase modulation

Model calculation

Linear transmittance at normal incidence

$$T = \left| \frac{4Y_0 Y_{\text{hole}} e^{iq_z h}}{(Y_0 + Y_{\text{hole}})^2 - (Y_0 - Y_{\text{hole}})^2 e^{2iq_z h}} \right|^2$$

$$\varepsilon_d = 2.25 + \chi^{(3)} \bullet \frac{A_{\text{u.c.}}}{A_{\text{hole}}} \bullet \frac{\left|\vec{E}_0\right|^2 \bullet T}{|S_0|^2}$$

- ➢ Permittivity of the Kerr medium
- ➢ E field enhanced by the area correction and (1/ S_0)^2

$$S_0 = \frac{\int_{\text{hole}} (\vec{E}^{\text{inc}})^* \bullet (\vec{E}^{\text{wg}}) dxdy}{\sqrt{\int_{\text{unit cell}} |\vec{E}^{\text{inc}}|^2 dxdy \bullet \int_{\text{hole}} |\vec{E}^{\text{wg}}|^2 dxdy}}$$

- ➢ S_0: Overlapping integral between incident wave & fundamental waveguide mode
- ➢ S_0: Characterizes the Q-factor and field enhancement inside the aperture

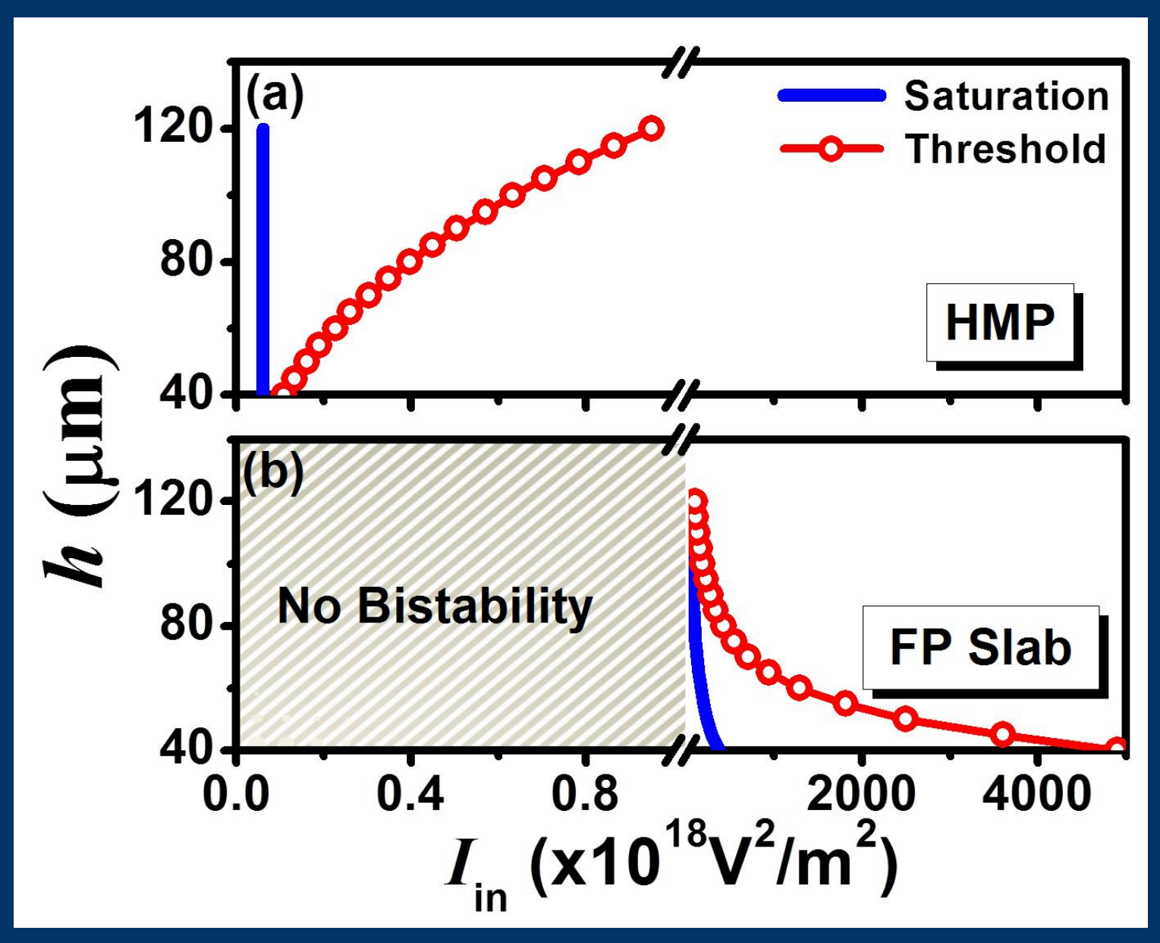
References:

•1. W. Chen, and D. L. Mills, Phys. Rev. B **35**, 524 (1987).

•2. S. W. Tang, B. C. Zhu, S. Y. Xiao, J. T. Shen and L. Zhou, Opt. Lett. **39**, 3213 (2014)

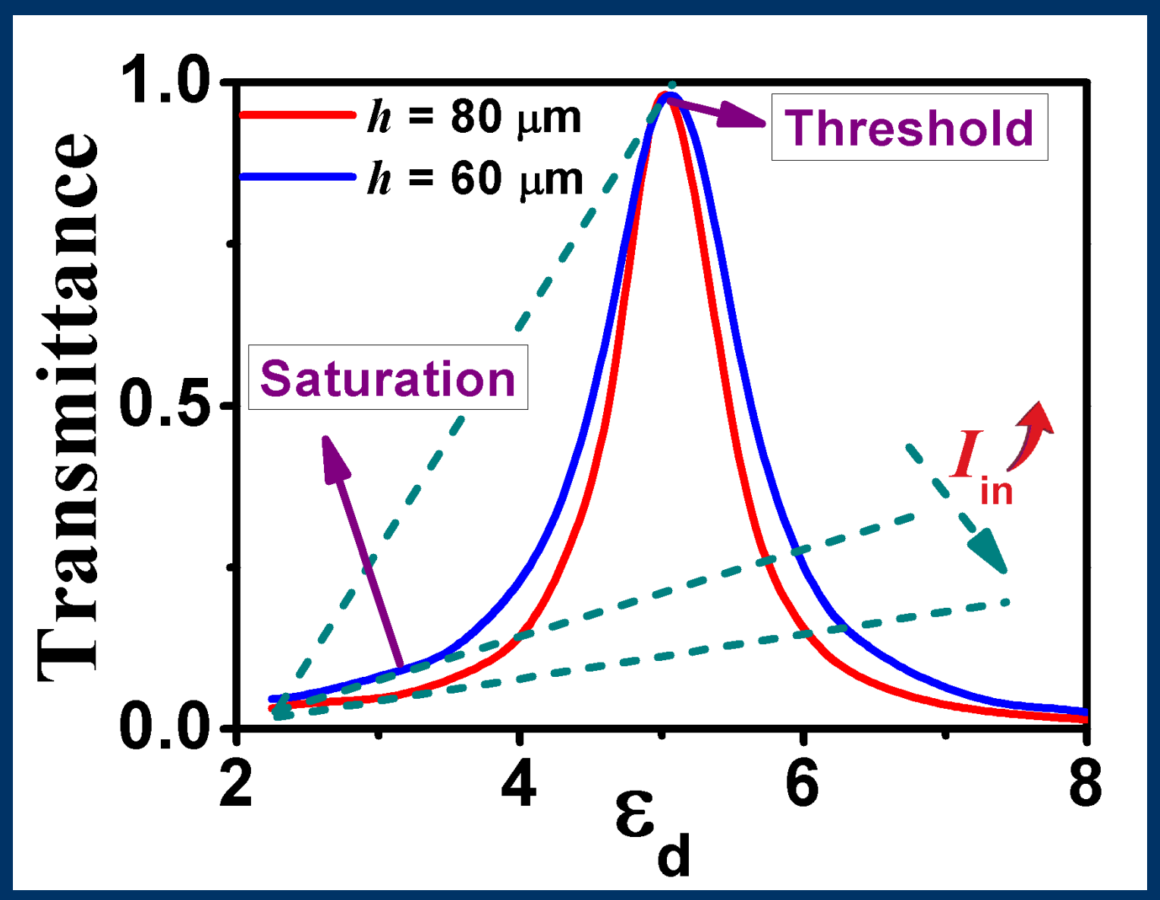
Discussions:

Film-thickness dependences of the threshold field and saturation field



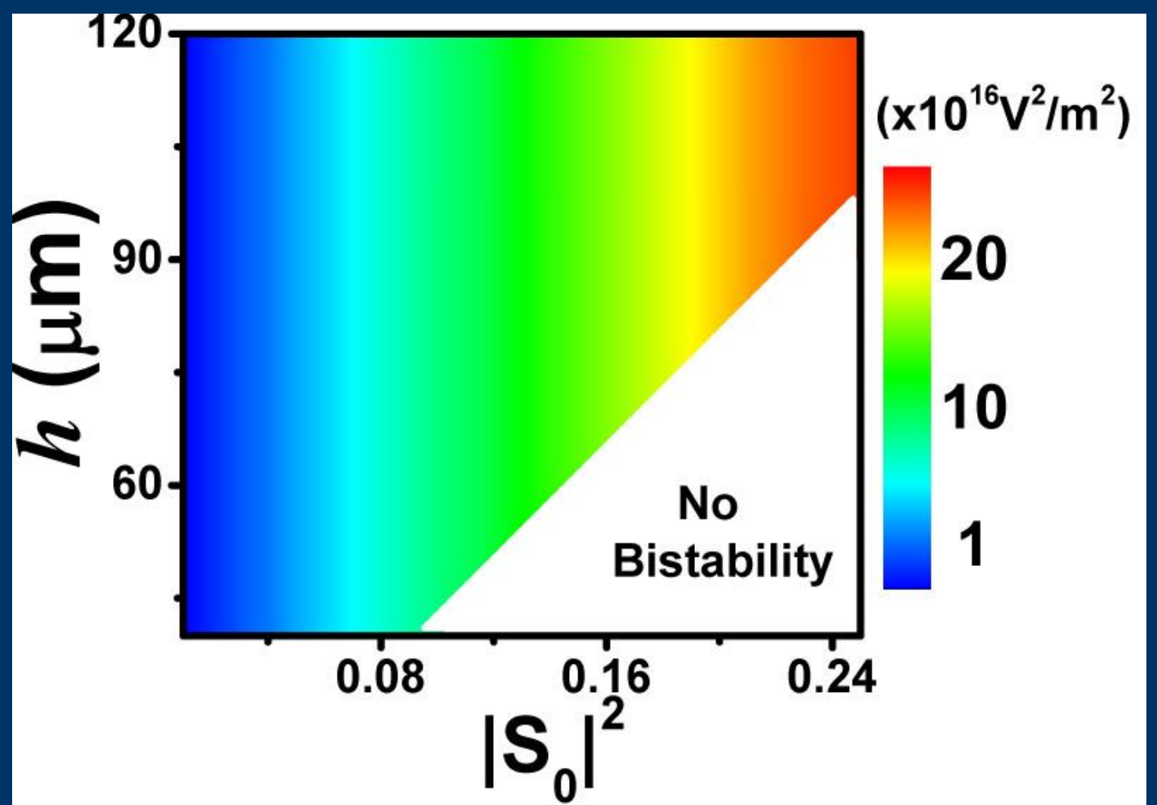
- ➢ Threshold of HMP much smaller than FP slab
- ➢ Mechanism is different: k=0 mode and field enhance

OB threshold and saturation fields in systems with different thicknesses



- ➢ Transmission peaks insensitive to film thickness *h*
- ➢ Transmission peak is narrowed when *h* is increased

Threshold versus S_0 and *h*



- ➢ Threshold decreases when S_0 becomes smaller
- ➢ Threshold is independent on *h*

Conclusions:

•Ultra-low bistability threshold (4.85x10^{16}*V*^{2}*/m*^{2}) that is 3500 times smaller than conventional optical bistable device

•Operation in a wavelength of 1500 micron (~0.2 THz), the thickness of the device can be as thin as 60 microns (1/25 of the wavelength)

•Device supports an operating bandwidth of 19 GHz