Slow Light with Zero Dispersion at the Edge of Honeycomb Photonic Crystals

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The velocity of light in vacuum, c, is approximately 3×10^8 m s^{-1}, fast enough to make 7.5 round-the-world trips in a single second, and to move a distance of 300 mm in 1 ns. This ultrahigh speed is advantageous for efficient data transmission between two points, whether they are separated on a global scale or on a single chip. However, it also makes control of optical signals in the time domain difficult. Slow light is a technology now being investigated as a means to overcome this problem.

Slow light had been achieved by a variety of method, including electromagnetically induced transparency (EIT), coherent population oscillation (CPO), stimulated Brillouin scattering (SBS), and photonic crystals (PCs). As one kind of method to slow down the light speed, PC waveguides have attracted much attention recently because they have many merits, such as ability of being integrated on optical chip, operating at room temperature.

Honeycomb PCs (HPCs) are an interesting photonic analogue of graphene. Here we show the slow light application of edge states at the zigzag edges of HPCs.

I. Slow light in photonic crystals

Group velocity of light: $v_g = \frac{d\omega}{dk}$,

where ω is frequency and k is wave vector of light.

Group index: $n_g = \frac{c}{v_g} = c\frac{dk}{d\omega}$ ⟶ Slow-down factor of c

Group index-bandwidth product (GIBP):

Limited

$$n_g = c\frac{dk}{d\omega} = \frac{d(n\omega)}{d\omega} = n + \omega\frac{dn}{d\omega}, \quad (k = \frac{\omega}{v} = \frac{n\omega}{c})$$

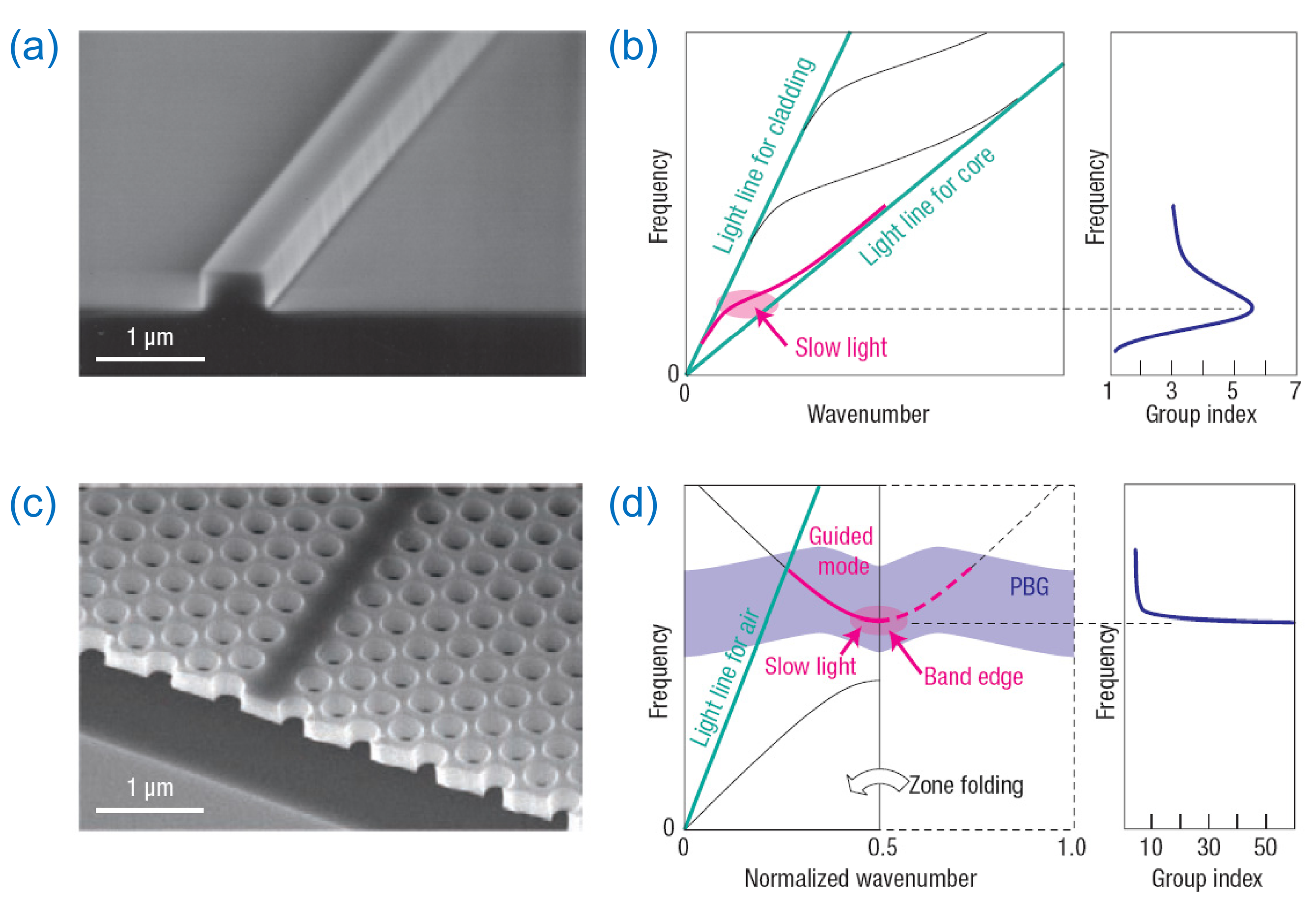
when $n_g \gg n$, $n_g \cong \omega\frac{dn}{d\omega} = \omega\frac{\Delta n}{\Delta\omega}$

$$\Rightarrow \quad n_g(\frac{\Delta\omega}{\omega}) \cong \Delta n$$

- Dispersive materials: EIT, CPO, SBS…
- Dispersive structures: PCs

Group-velocity dispersion (GVD): $\frac{d(v_g^{-1})}{d\omega} = \frac{d^2k}{d\omega^2}$

- Dispersion-compensated slow light
- Zero-dispersion slow light



Waveguides, photonic bands and group-index characteristics.

II. Slow light in edge state waveguides

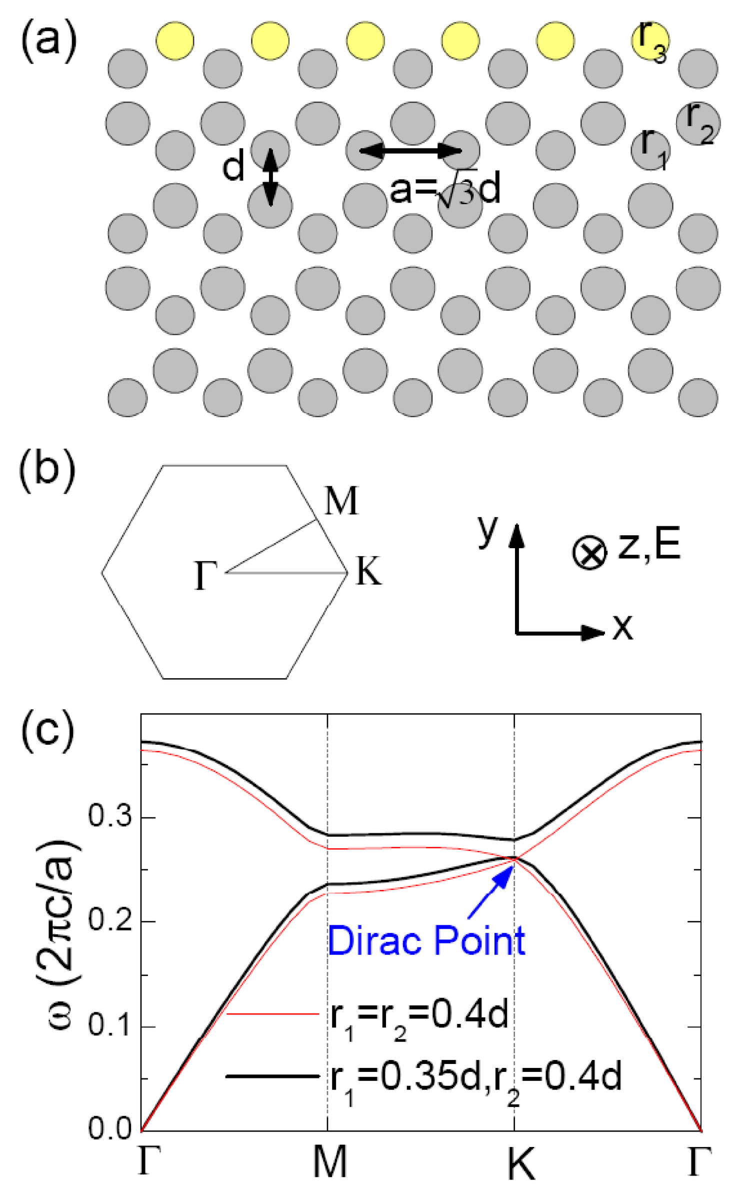


Fig. 1. Honeycomb lattice of dielectric rods in air and TM band structure.

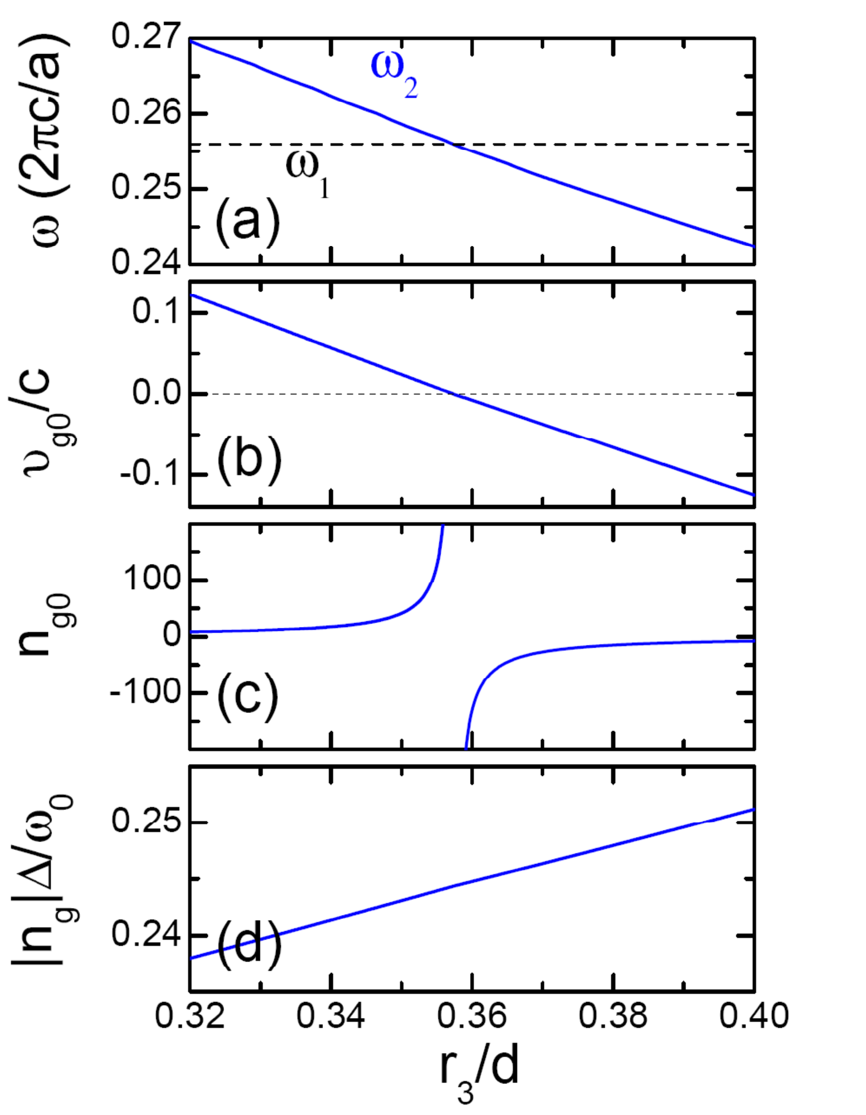


Fig. 4. Frequencies, group velocity, group index and GIBP as functions of the radius r_3 of the rods at the edge.

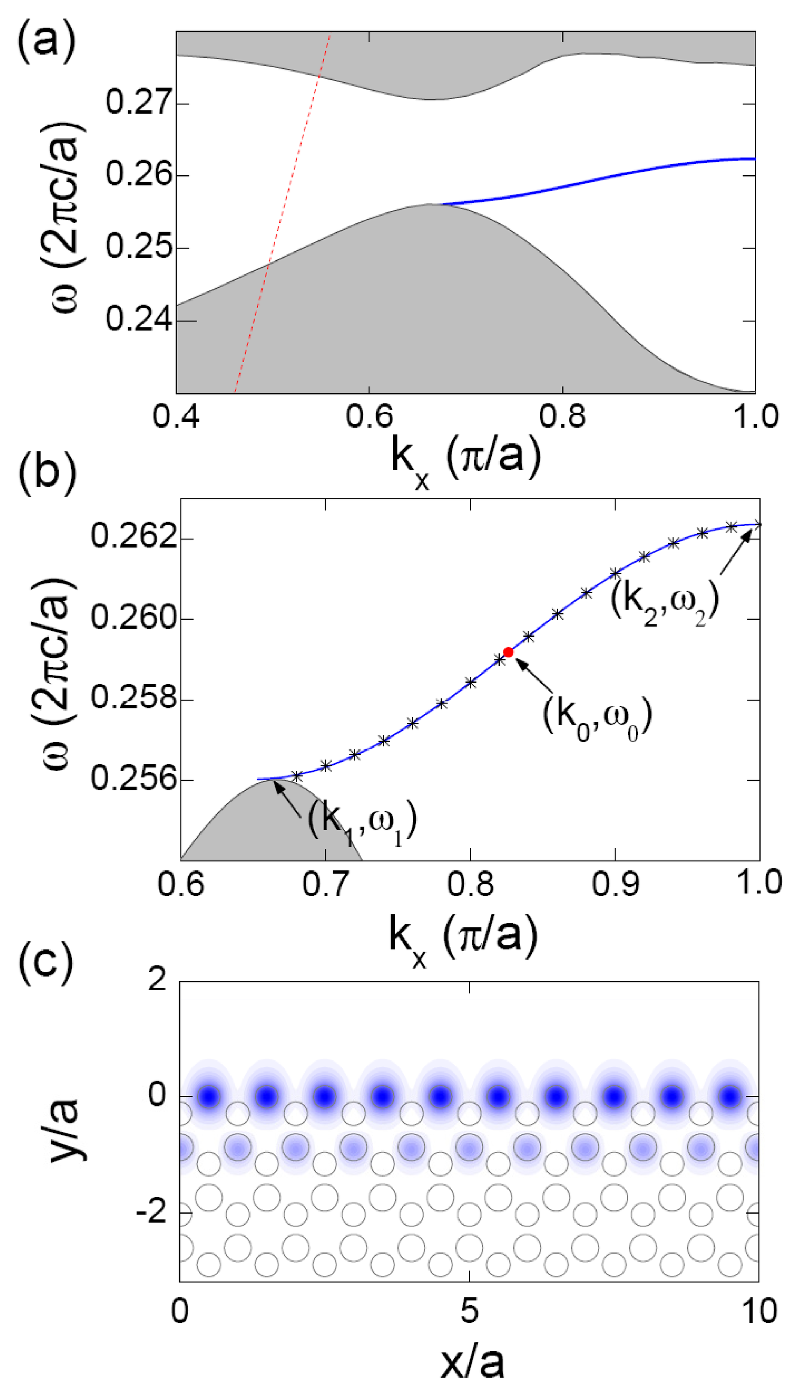


Fig. 2. Sinusoidal dispersion and field distribution of edge states in HPCs.

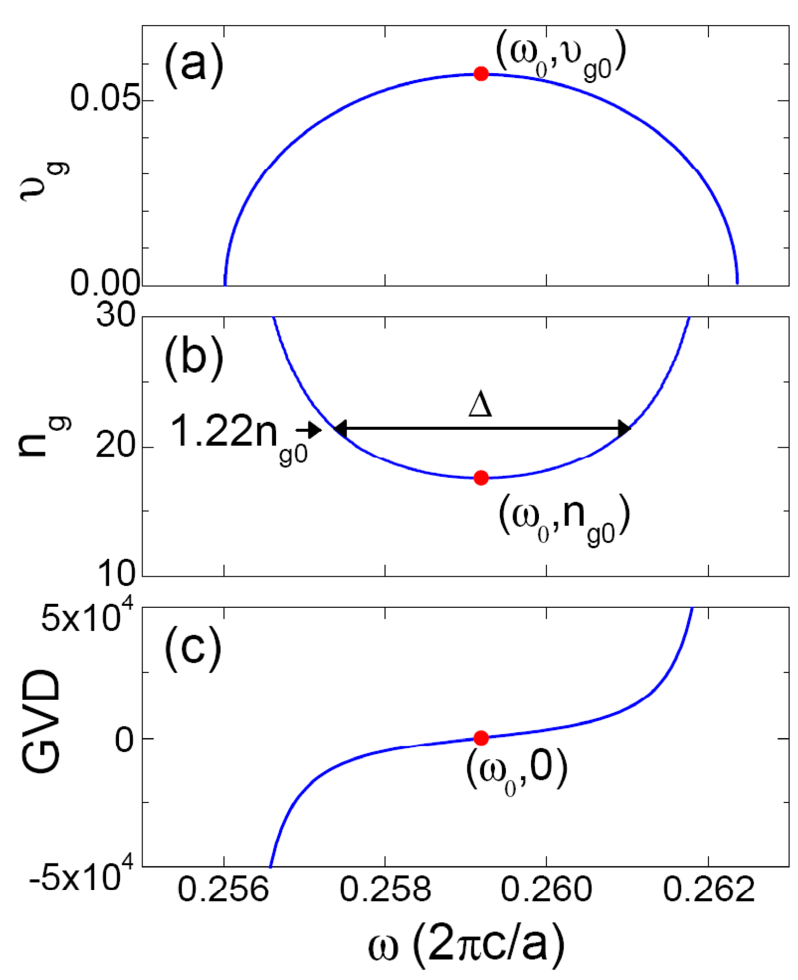


Fig. 3. Group velocity, group index and GVD for the edge states in Fig. 2(b).

III. Conclusions and references

- In summary, we have found that the zigzag edge states of HPCs can possess a sinusoidal dispersion curve below the light line in vacuum. The dispersion curve can be tuned to be very flat with using appropriate edge parameters. Hence, a light pulse can be slowed down without a radiation loss and group velocity dispersion by the HPC zigzag edges.
- Compared with conventional PC coupled optical resonator waveguide, our slow-light system can present a larger group index bandwidth product and possibly a longer time delay. These results may find applications in on-chip optical buffers and enhanced light-matter interaction.

- *References: Toshihiko Baba, Slow light in photonic crystals. Nature photonics 2,465(2008).*
  Masaya Notomi, Eiichi Kuramochi and Takasumi Tanabe, Large-scale arrays of ultrahigh-Q coupled nanocavities. Nature photonics 2,741(2008).
  C.F. Ouyang, B.Q. Dong, X.H. Hu, X.H. Liu and J. Zi, Slow light with zero dispersion at the edge of a honeycomb photonic crystal. To be published.