Topological Corner State Laser in Kagome Waveguide Arrays

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In comparison with conventional lasers, whose stability may be affected by perturbations, such as defects and disorder, topological lasers may be remarkably stable when they lase in topologically protected edge states. In this work, we predict that corner laser can be implemented in a new continuous system, which is based on Kagome [1] waveguide arrays, where localized gain can be selectively provided in different waveguides, and where uniform losses, two-photon absorption, and focusing nonlinear interactions are present. Even though lasing in 0D corner states has been recently reported in photonic crystal cavities [2-4], this work suggests a new platform based on the continuous waveguide array in cavity-free configuration. We employ localized gain, which, when applied in different corners of our structure, offers unique advantage of highly selective excitation of bulk, edge, or corner nonlinear topological states in higher-order topological insulator. The possibility of such selective excitation in our truly two-dimensional system is a nontrivial result by itself taking into account complex spatial shape of the considered structure. We report on completely stable corner state lasing and bistability of the edge state lasing that can only be observed in the nonlinear medium. The detailed analysis of stability of lasing modes is provided for different values of linear gain and two-photon absorption coefficients.

To characterize lasing corner and edge state families in our system, we plot their peak amplitude $|\psi(\mathbf{r})|_{\text{max}}$ and nonlinear energy shifts $\varepsilon$ as functions of gain amplitude $p_{\text{im}}$ in Fig. 1, for different two-photon absorption coefficients $\alpha$. Corresponding gain landscapes are presented for each case too (panels denoted as case1 and case3). In both cases stationary nonlinear modes appear when gain amplitude $p_{\text{im}}$ exceeds corresponding lasing threshold, for example, $p_{\text{im}}^{\text{th}} \sim 0.078$ in the case1 (gain applied in the corner, where topological state resides). Such nonlinear corner states are of topological origin since they bifurcate from 0D linear topological corner modes. In the top two panels in the right column in Fig. 1 (a) we show field modulus distributions for corner lasing states at $\alpha = 0.4$ for different gain amplitudes, corresponding to the red dots. One can see that such states are very well localized and that most of their energy is concentrated in the top-right corner site. In contrast, when gain is provided in the top left corner of the array [see the bottom panels in the right column of Fig. 1 (b)], the lasing threshold $p_{\text{im}}^{\text{th}} \sim 0.225$ is substantially larger than the threshold obtained for the corner state in the case1. It is remarkable that by choosing gain location in this system one can selectively excite either 0D corner or 1D edge states. This illustrates a rich variety of lasing regimes that can be observed in our structure that would not be available in single-waveguide geometries. Nonlinear families corresponding to different absorption coefficients for the case3 are displayed in the left panel of Fig. 1 (b). Interestingly, the bistability domain is encountered for edge states in the case3, where three solutions can coexist for the same $p_{\text{im}}$ value. The encountered bistability offers the unique advantage to achieve lasing in the edge states with different internal structures and amplitudes for certain $p_{\text{im}}$ values. In the top panels in the right column of Fig. 1 (a), we illustrate representative $|\psi(\mathbf{r})|$ distributions from the lower and upper branches of bistability curve corresponding to the red dots.

![Fig. 1](image-url)

Fig. 1 Nonlinear lasing state families. Maximal amplitude $|\psi_{\text{max}}|$ and propagation constant $\varepsilon$ of the nonlinear lasing mode versus gain amplitude $p_{\text{im}}$ for two different locations of the amplifying channel (a) case1, (b) case3 and nonlinear absorption coefficients $\alpha = 0.1, 0.2, 0.3, 0.4$ (in all plots left outermost curve corresponds to $\alpha = 1.0$, while right one to $\alpha = 0.4$). Stable branches are shown black, unstable branches are shown red. Red dots correspond to $|\psi(\mathbf{r})|$ distributions shown in the top row. Bottom row schematically shows location of channel with gain in the array.

References
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