NEWS AND VIEWS

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Colloidal quantum dot lasers and hybrid integrations

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Colloidal quantum dots (CQDs) are semiconductor nanocrystals with diameters about 2 to 20 nm. At such nanoscales, the CQDs exhibit obvious quantum and dielectric confinement effects[1]. The CQDs are usually composed of II–VI, III–V, and IV–VI semiconductors fabricated by the low-cost wet chemical synthetic methods. The emission wavelengths of CQDs, which can be easily tuned by the sizes, shapes, and compositions, have already covered the whole range of the visible and near-infrared (NIR) spectra (from 440 to 1530 nm). Owing to the low-cost fabrications, high quantum yields (QYs~100%), tunable emission wavelengths, and outstanding stability, the solution-processable CQDs can act as the nanoscale building blocks with large gains, and they have attracted enormous attention in the lasing applications in the past decade.

Besides the gain materials, the optical cavities are vital to the lasing action. Recently, great efforts have been made to fabricate various optical cavities to realize the CQD lasers, including the Fabry–Pérot (FP) cavities, whispering-gallery-mode (WGM) cavities, distributed feedback (DFB) cavities, random cavities, and photonic crystal cavities. These optical cavities provided the feedbacks and mode selecting, while the CQDs played the role of the gain materials. Under the pump beam, the lasing action occurred. In practical applications, the development of simple and low-cost manufacturing methods to achieve small on-chip CQD lasers are urgent and appealing for photonic integrated circuits (PICs). Recently, Chen's group exploited the simple drop-casting and water-dripping method to manufacture the high-quality CQD microplates with various shapes and sizes[2]. Under low pump thresholds, the multi- and single-mode CQD lasers were experimentally realized. Moreover, the CQD microplate lasers were easily integrated with waveguides on chips.

The on-chip laser sources are one of the key components in PICs, which are the optical analogies of the electric circuits but possess much higher transport speeds and much broader bandwidths. The hybrid integration of the on-chip laser sources, waveguides, optical processing components (e.g., splitters, filters, amplifiers, and modulators), and detectors can greatly increase the performances of the functional PICs, as shown in Fig. 1, where the different colors denote the different materials. The reason is that every nanophotonic device possesses its optimal materials and structures. The hybrid integration can combine the advantages of all kinds of materials and structures. For example, the CQDs are an ideal gain material, but they are not suitable for light guiding because of the large absorption at the lasing wavelengths[2]. Moreover, the sizes of CQD-based nanophotonic devices can't break the diffraction limit. It is known that surface plasmon polaritons supported by the metallic nanostructures show subwavelength field confinements[3]. The hybrid integration of on-chip CQD lasers and subwavelength plasmonic waveguides can combine both the advantages of the high performances of the small CQD lasers (large gain, solution-processibility, low threshold, and high quality factor) and the plasmonic waveguides (deep subwavelength confinement). However, the precise hybrid integration is a challenge owing to the complexity of the hybrid structures and the damageability of the gain media in the multistep micro/nanofabrications. To address the fabrication problem in the hybrid integration, Chen's group developed the dark-field optical imaging technique with a position uncertainty of about 21 nm. By employing this simple and precise technique together with the high-resolution electron beam lithography, the small CQD lasers were accurately aligned with the silver nanowires without any damages[4]. As a result, the deep-subwavelength coherent sources (multimode, one-color single-mode, or two-color single-mode) with a mode area of only $0.008\lambda^2$ were output from the hybrid structures. This precise hybrid integration method would greatly facilitate the developments of the complex functional hybrid photonic–plasmonic circuits. For the hybrid integration of other materials (especially for new materials) and structures, the exploitation of more novel fabrication methods is eagerly desired.

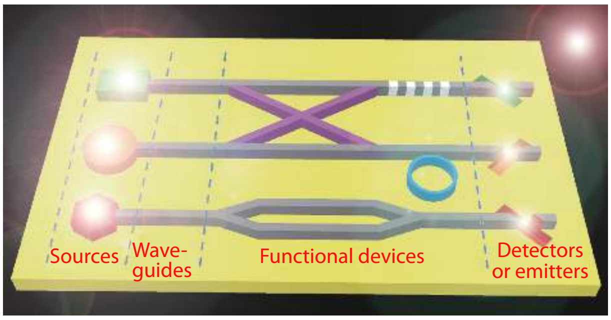

Fig. 1. (Color online) Hybrid integration in photonic integrated circuits, which consist of the on-chip laser sources, waveguides, functional devices, and detectors (or emitters). The different colors denote the different materials.

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