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Original article

One-step synthesis of organic microwire-disk interconnected structure for miniaturized channel filters

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ABSTRACT

Miniaturized channel filters are in high demand for many applications such as photonic integrated circuits, information-based technology, and platforms for investigation of light–matter interactions. Recently, several photonic schemes have been proposed to achieve nanofilters, which require sophisticated growth techniques. Here, we have fabricated microdisk whispering-gallery-mode (WGM) resonators through controlled assembly of organic materials with an emulsion-solvent-evaporation method. Based on this emulsion assembly method, the diameters of microdisks can be easily controlled, and more importantly, a microwire-disk interconnected structure is able to be constructed via one-step assembly. This microwire-waveguide-connected microdisk heterostructure can be utilized as a channel drop filter. Our results have demonstrated a facile way to achieve flexible WGM-based photonic components which can be integrated with other functional devices.

1. Introduction

Achieving filters in micro/nanoscale cavities is crucial to realize promising applications in on-chip optical communication [1–3]. With the development of fabrication techniques, a series of photonic materials with various structures such as nanofibers [4], nanorings [5] and nanotubes [6], have been readily synthesized to realize filtering. In optical resonators, whispering gallery mode (WGM) cavities with tight confinement of photons [7–11] allow profound engineering of light emission to achieve specific functionalities [12–20]. Practical applications of these artificial optical geometries are still hindered for their inconvenient fabrication, which requires sophisticated planar epitaxial technology to incorporate with optical gain medium.

With advantages in chemical versatility, good processability and flexible nature, organic materials have been utilized to fabricate many kinds of micro/nano-assemblies [21,22] including highly bent waveguides [23], platelets [24], hemispheres [25] and also rings [26], which have already served as WGM resonators. Moreover, the ease of molecular design [27] and chemical compositing [28] enables organic matrixes to incorporate with various optical dyes to display tunable and diverse photonic properties [29]. Therefore, organic materials are ideal candidates for the fabrication of flexible WGM microresonators. To integrate with other functional components, the resonating light in WGM resonators should be efficiently exported [30]. It is known that wire-disk connected structure provides a promising approach to break the rotational symmetry and efficiently collect the WGM signals. Up to now, several wire waveguide-coupled WGM resonators have been constructed using sophisticated multistep procedures. The ever-increasing demand in high-speed photonic processing chips requires more facile and controlled ways for waveguide-coupled microdisks.

In this work, we have proposed a controlled emulsion assembly strategy to fabricate flexible organic microdisk WGM resonators. The diameters of the microdisks can be finely tuned by altering the micelle size of the emulsion during the assembly process. The phosphorescent dye fac-tris(2-phenylpyridine) iridium ($Ir(ppy)_3$) has been doped in the microdisks in order to realize WGM spectral modulation of the outcoupled light signals. More importantly, waveguide-coupled WGM resonators comprising microdisks and microwires have been obtained by one-step assembly via a controllable phase separation between the doped dye and the matrix material, which acted as a channel drop filter. The results offer a facial way to construct flexible microwire-disk interconnected structures and enlightenment for their potential applications in high-speed and high-density photonic processing chips.

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2. Results and discussion

2.1. Microdisk resonators

The flexible composite microdisks are obtained by an emulsion-solvent-evaporation method, as shown in Fig. 1. In the process, polystyrene (PS) was chosen as a host material for the microdisk due to its high transparency, thermal stability against oxidization, and outstanding flexibility, which is suitable to form a high-quality and stable microresonator. Fac-tris(2-phenylpyridine) iridium $Ir(ppy)_3$ (Fig. S1 in Supporting information) was selected as a dopant because of its high luminescence efficiency and broad spectral range of photoluminescence (PL). First, PS and $Ir(ppy)_3$ molecules were dissolved in *N,N*-dimethylformamide (DMF), and then slow precipitation of PS was induced by adding a small amount of water [31]. After the sonication, the polymer molecules with low crystallinity prefer to aggregate into spherical micelles [32], because of the interfacial tension. At the same time, the Ir (ppy)$_3$ were doped in the PS matrix through molecule interactions. Finally, the composite microdisks were obtained on the substrate after the evaporation of solvents.

The top- and side-view SEM images in Fig. 2 verify the disk-shape structure with a perfect circular boundary and ultra smooth surface. The thickness of the microdisk is about 2 μm, which is suitable to confine the light in the PS matrix with negligible leakage to the substrate. According to the assembly process, the diameter of the microdisk is in direct proportion to the size of the micelles in the emulsion solution that strongly relies on the interfacial tension between PS and the solvent. When more water is added, the size of the polymer micelles tends to increase, because large micelles have small specific surface areas and enable to reduce the interfacial energy of the system. Hence, as illustrated in Fig. 3a–c, the microdisk diameter ranging from 3 μm to 15 μm can be easily controlled by changing the amount of water (from 10 μL/mL to 30 μL/mL). The corresponding PL microscopy images in Fig. 3d–f demonstrates green fluorescence emission under UV excitation, confirming uniform doping of the $Ir(ppy)_3$ dye in the PS matrix.

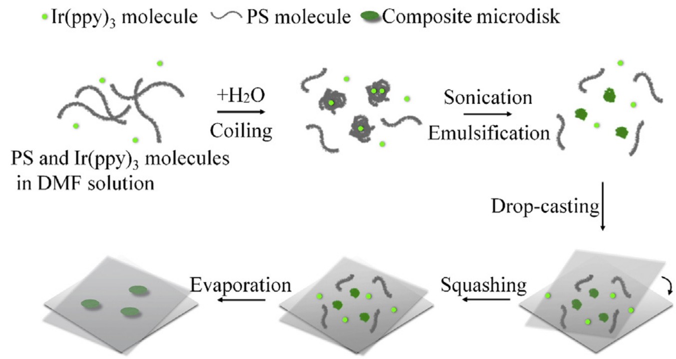

Fig. 1. Schematic diagram of the composite microdisks fabrication process.

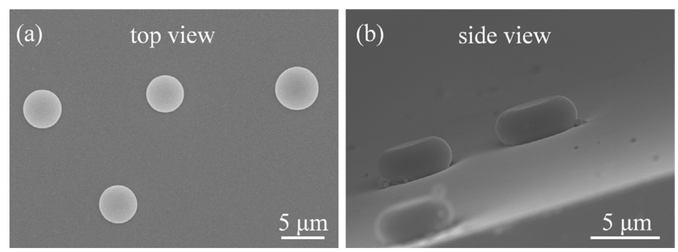

Fig. 2. Top (a) and side view (b) SEM images of the $Ir(ppy)_3$/PS microdisks.

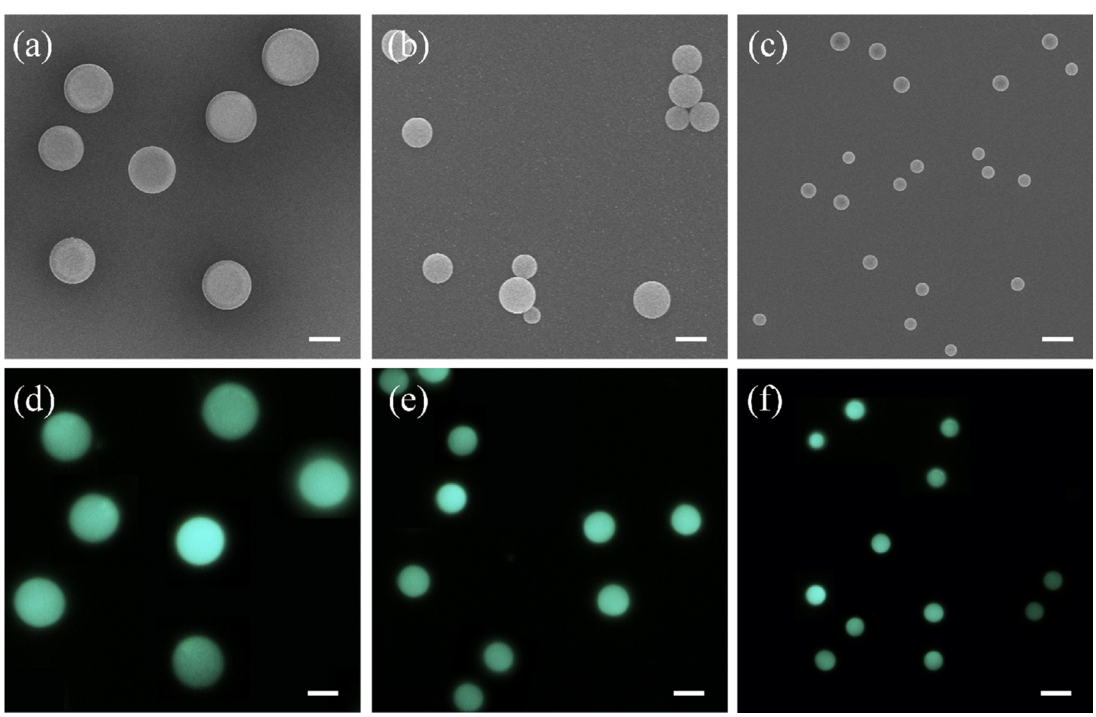

Fig. 3. (a–c) SEM images of the $Ir(ppy)_3$/PS microdisks prepared by adding water (10, 20, and 30 μL, respectively) to the PS solution (1 mL). (d–f) PL images of the microdisks excited with the UV band (330–380 nm) light source. All scale bars are 10 μm.