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Bio-Photonic Waveguide of a DNA-Hybrid Semiconductor Prismatic Hexagon

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A successful identification of DNA–DNA recognition, based on the waveguide effect of a 1D hybrid prismatic hexagon crystal interfacing of DNA with an organic semiconductor is achieved. This bio-hybrid 1D crystal simultaneously discerns the complementary case at its one end against a 1-mer mismatch in 27-mer nucleic acid sequence at the other end. The loss coefficient value of this waveguide is estimated to be 0.159 μm^{-1} for the perfect match, which is a stark discrepancy compared to 0.244 μm^{-1} for the 1-mer mismatch, implying waveguide performance with a higher efficiency. These results demonstrate successfully that multiple biological interactions can be realized by the optical waveguide of the single 1D bio-hybrid-crystal and will push this class of materials into bio-related applications.

Advancement in the field of telecommunications, especially optical waveguide technologies at nano-to-micro scales, requires materials that can avoid interferences from external electromagnetic fields.[1–3] Organic semiconductor molecules are attractive photonic materials owing to their high refractive indices that enable rapid information transfer while maintaining minimal optical losses and heat generation.[4–7]

The self-assembly of the π-conjugated organic molecules is a promising fabrication technique for organic micro- and/or nanocrystals with well-defined shapes, tunable sizes, and defect-free structures. Among various micro/nanocrystals, 1D structures have been demonstrated to be effective building blocks for unique functional devices,[5] such as lasers,[8] waveguides,[9] field-effect transistors,[10] and solar cells.[11]

1D crystals composed of highly ordered π-conjugated organic molecules can generate more excitons upon excitation.[12] Such a crystal with a higher refractive index than its environment can serve as an efficient optical waveguide to transmit photons or optical microcavities so as to confine photons.[13–17] Additionally, if the organic molecular crystals meet the following conditions, it is beneficial to the active light transduction,[18,19] such as: (i) large Stokes shifts to avoid re-absorption of propagating light, (ii) well-ordered crystallinity to ensure less scattering at domain boundaries, and (iii) smooth surface to reduce scattering loss during light propagation.[20–24]

Examples of 1D organic crystals of microtubes,[21,22] microwires,[23] and nanorods[24] have demonstrated excellent optical waveguide nature. Since Hardy et al. first reported an organic-film-coated optical waveguide sensor for vapor detection in 1975,[25] applications based on the waveguide effect of 1D materials have been achieved[26,27] including remote sensing,[28–31] optomechanical transduction,[32] and optoelectronic interconnectors.[33] Yet, the design and fabrication of 1D crystals exhibiting exotic functions remain a great challenge.

Unfortunately, there has been less research done in the use of such 1D waveguides for sensing biological objects. This is mainly due to a dilemma of being able to form stable surface modifications with biological moieties while preventing scattering loss in the 1D organic materials. Hence, to extend waveguides further into functional remote biosensing, novel interfacing of bio-molecules with 1D organic materials preserving their unique waveguide nature is much desired.

Our group first reported a simple method for fabricating hexagonal 1D crystals of semiconducting tris (8-hydroxyquinoline) aluminium (Alq3) using single-strand DNA (ssDNA) molecules.[34] In a bulky solution phase of ssDNA-embedded crystals, the photoluminescence (PL) intensity is enhanced when complementary target DNAs (tDNAs) are recognized.[35] A typical organic light-emitting diode (OLED) material, Alq3, was endowed with a bio-recognition function, for the first time, by means of uniquely interfacing it with ssDNA. These hybrid-crystals can also detect metal ions by selecting an appropriate

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