Single organic molecule coupling to a hybrid plasmonic waveguide

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Efficient photon sources will enable many quantum technologies. Single dibenzoterrylene (DBT) molecules are promising photon sources, but often emit in an unknown direction making photon collection challenging. Dielectric structures redirect emission into single optical modes [1], but are relatively large due to the diffraction limit of light. Plasmonic devices, such as antennae, can concentrate the electromagnetic field at the site of an emitter on a surface in volumes below the diffraction limit and redirect emission into well-controlled directions, but often suffer from losses. Recently, planar dielectric antennae have shown promise for redirecting emission [2], however often they do not provide single mode operation or compatibility with integrated photonics.

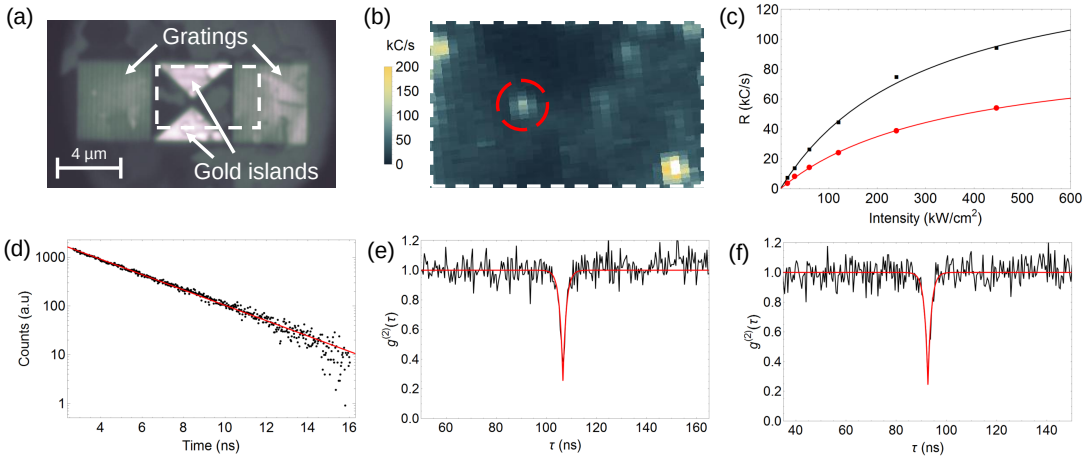

Fig. 1: (a) White-light image of a HPW showing input/output grating couplers and anthracene crystals on the surface. (b) Molecule fluorescence from the dashed box in (a). (c) Saturation curves for the molecule indicated with a red dashed circle in (b), showing count rates collected from the confocal microscope (black squares) and from a grating coupler (red circles). (d) Pulsed laser measurement of the molecule excited state lifetime. (e) $g^{(2)}(\tau)$ measured from the microscope only and (f) $g^{(2)}(\tau)$ measured from the grating and microscope.

Here we present a hybrid dielectric–metal approach in coupling a single molecule to an optical mode in an integrated planar device. We designed and fabricated a hybrid plasmonic waveguide (HPW) consisting of a dielectric slab with a nanoscale gap patterned in gold on the surface, as shown in Fig. 1(a). Replacing the silicon layer used in our previous work [3] with titanium dioxide (TiO_2) allows operation at ~ 785 nm, the emission wavelength of DBT. Light propagating in the TiO_2 layer passes through the gap between the islands of gold. The width of the gap controls mode confinement: when the gap is <100 nm the propagating mode is mainly in the gap providing strong confinement; but when the gap is wider the mode decouples from the gold and propagates mainly in the TiO_2 with low loss. We deposited DBT-doped anthracene crystals on the surface (Fig. 1(a)) using a supersaturated vapour growth technique [4]. Using confocal fluorescence microscopy we found a DBT molecule positioned near the gap (Fig. 1(b)). We then measured the saturation intensity of the molecule (Fig. 1(c)) to be $I_{sat} = 325(27)$ kW/cm^2. Illuminating the molecule with a pulsed laser (Fig. 1(d)) we measured the lifetime of the molecule to be 2.74(2) ns. Under CW excitation we measured the second-order correlation function $g^{(2)}(\tau)$ of the light emitted directly into the microscope. This shows clear anti-bunching (Fig. 1(e)) with $g^{(2)}(0) = 0.25(6)$ proving this to be a single molecule. By detecting photons simultaneously from the microscope and from the grating coupler we measured $g^{(2)}(0) = 0.24(6)$ (Fig. 1(f)), demonstrating that this single molecule was emitting into the waveguide mode. By measuring the optical losses in our setup we calculated the coupling efficiency from the molecule to the HPW to be $\sim 22\%$. This method provides a route to building waveguide sources of photons in planar integrated quantum photonic circuits for applications in quantum technology.

References

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