Mode-Matching Method for Efficient Coupling and Near-Unity Absorptance in a Single Tapered Semiconductor Nanowire

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Advances in nanophotonic systems have led to the development of optoelectronic devices at the nanoscale for integrated photonics and quantum technologies. Near-room temperature semiconductor nanowire-based detectors show promise as high-performance nanoscale optoelectronic platforms [1,2]. Single nanowires remain of particular interest, with desirable optical and electrical qualities and have already demonstrated promise as avalanche photodiodes [3]. High coupling and absorption efficiencies are critical in high-performance optoelectronics and remain a core challenge to the single nanowire platform [2]. In this work, we demonstrate under mode matching conditions, an incident Gaussian source is coupled to the fundamental circular waveguide mode (HE_{11}) for the realization of a tunable, selective, vertical single-tapered semiconductor nanowire absorber [Figure 1]. Our numerical calculation shows, within the bandgap of the material, an InP tapered nanowire can absorb up to 99% of the incident light with spectral tunability for selective absorption, achieved by controlling the diameter of the nanowires. We experimentally show perfect coupling from a mode-matched single quantum-dot embedded nanowire (NWQD) source which has not been reported before [4]. Our work paves the way for the realization of a near-unity absorber which can be used as the first step towards future designs of nano-optoelectronic devices such as single-photon detectors and NWQD devices with enhanced efficiencies.

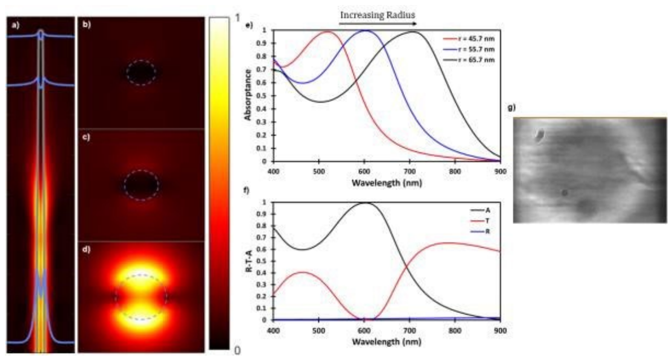

Fig. 1: a-d) The electric field profile of the incident light as it travels through a single tapered nanowire (NW). e) Absorptance spectra achieved for NWs with three different radii with near-unity absorptance. f) The absorptance (A), transmittance (T), and reflectance (R) spectra of the mode-matched tapered nanowire absorber. g) Fourier transformed image of the output spatial mode HE_{11} of a NWQD emission.

References

[1] Sun, J. *et al.* “Recent Advances in Group III-V Nanowire Infrared Detectors”, *Advanced Optical Materials* **6**, 1800256 (2018).

[2] Li, Z. *et al.* “Review on III-V Semiconductor Single Nanowire-Based Room Temperature Infrared Photodetectors”, *Materials* **13**, 1400 (2020).

[3] Bulgarini, G. *et al.* “Avalanche amplification of a single exciton in a semiconductor nanowire”, *Nature Photon* **6**, 455–458 (2012).

[4] Anttu, N. “Absorption of light in a single vertical nanowire and a nanowire array”, *Nanotechnology* **30**, 104004 (2019).