Compact plasmonic-photonic coupler for efficient low dispersion and directional coupling

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Introduction

With the rise of integrated silicon photonic circuits, the problem of efficiently coupling light in the telecommunication band into photonic waveguides has become a relevant one. While grating couplers typically have efficiencies in excess of 20%, this comes with the trade-off of complicated optimized designs and bulky device sizes. Moreover, grating couplers suffer high angular sensitivity and the problems of high dispersion and short bandwidths. The other efficient coupling approach, prism couplers, require complicated and bulky off-chip arrangements and have a limited range of permittivites for coupling to semiconductor waveguides. For these reasons, the simplistic method of direct-end fire excitation is the most common method of coupling despite efficiencies as low as 1%. The potentially device damaging chip cleaving required by end-fire coupling is considered necessary consequence. In [1], we proposed a compact plasmonic-photonic coupler consisting of gold nanoparticles positioned above a silicon photonic waveguide that exhibited efficient and low dispersion broadband coupling between free-space radiation and the photonic waveguide with a compact device footprint. Here we present the experimentally realized devices as depicted in Figure 1.

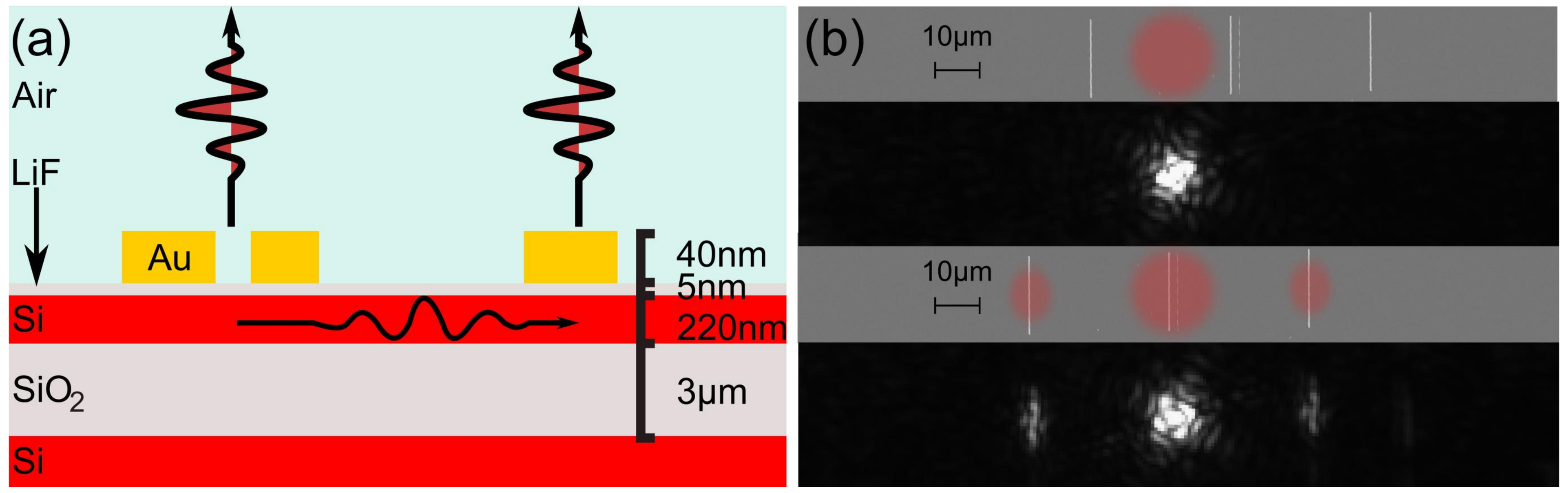


Figure 1: a) Schematic of the realized device. b) Depiction of coupling when the input beam is off/on the in-coupler.

Experimental Coupling Efficiency

Figure 2(a) shows the out-coupled power for 330/225nm and 330/330nm in-couplers at various relative phase between particles. The highest efficiency was found for the asymmetric particle pair separated by 600nm at ~19%, assuming an out-coupling efficiency of 30%.

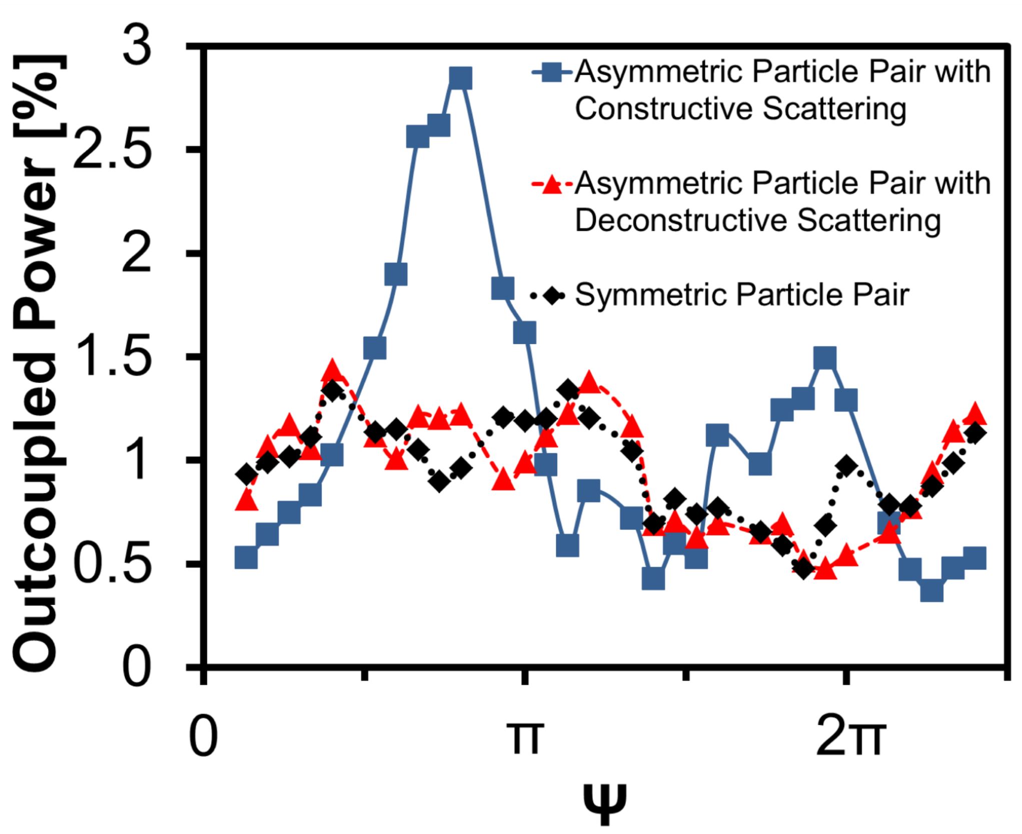


Figure 2: Measured out-coupled power as a function of relative phase (spacing) between particles at λ=1.5μm for the 330/225nm and 330/330nm particle couplers.

Broadband Coupling

The broadband nature of these couplers, as compared to the original theoretical predictions seen in Figure 3(a), was measured using a supercontinuum generated white light source and is explored in Figure 3(c-d). It was found that the formation of standing waves in the buried oxide layer had a profound effect of the in- and out- coupling spectrum, but the coupling spectrum still covers over 400nm.

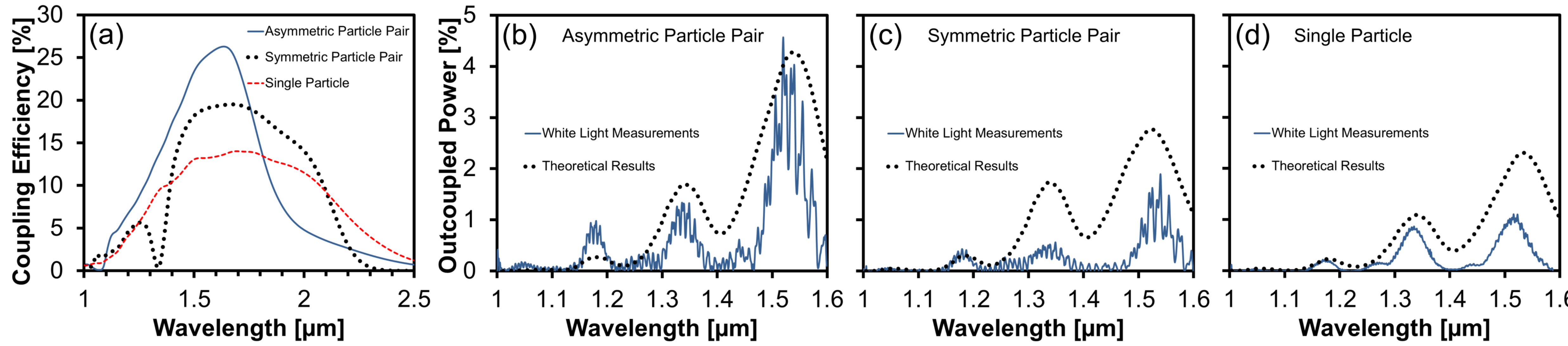
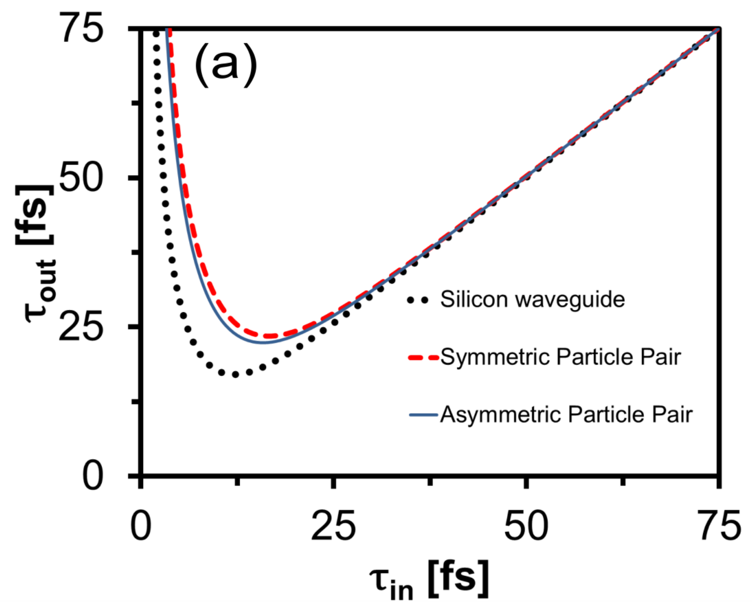
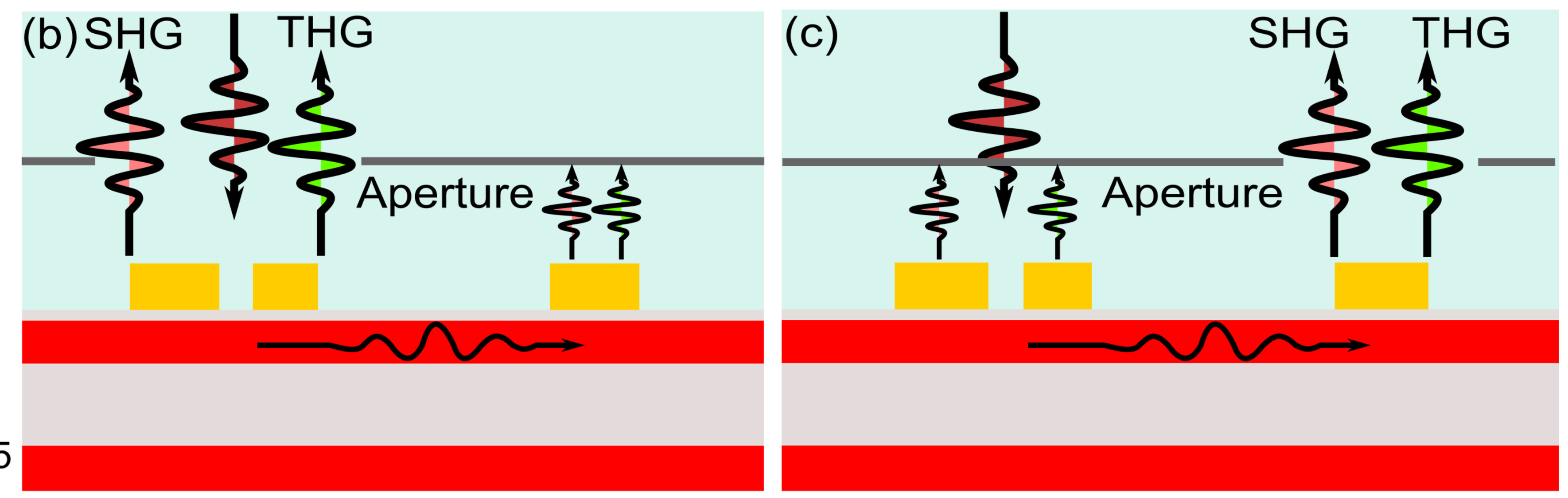


Figure 3: (a) Original broadband predictions of in-coupling efficiency. Broadband measurements for the (b) asymmetric particle pair, (c) symmetric particle pair, and (d) single particle in-couplers compared to theoretical predictions.

Nonlinear Measurements

The predicted low dispersion of the couplers was verified, as seen in Figure 4, by coupling short 150fs pulses into the couplers and measuring the resultant second and third harmonic generation (SHG, THG) as seen at the in-/out-couplers. From the THG signal, the in-coupling efficiency can be estimated at 21% at λ=1.5μm.





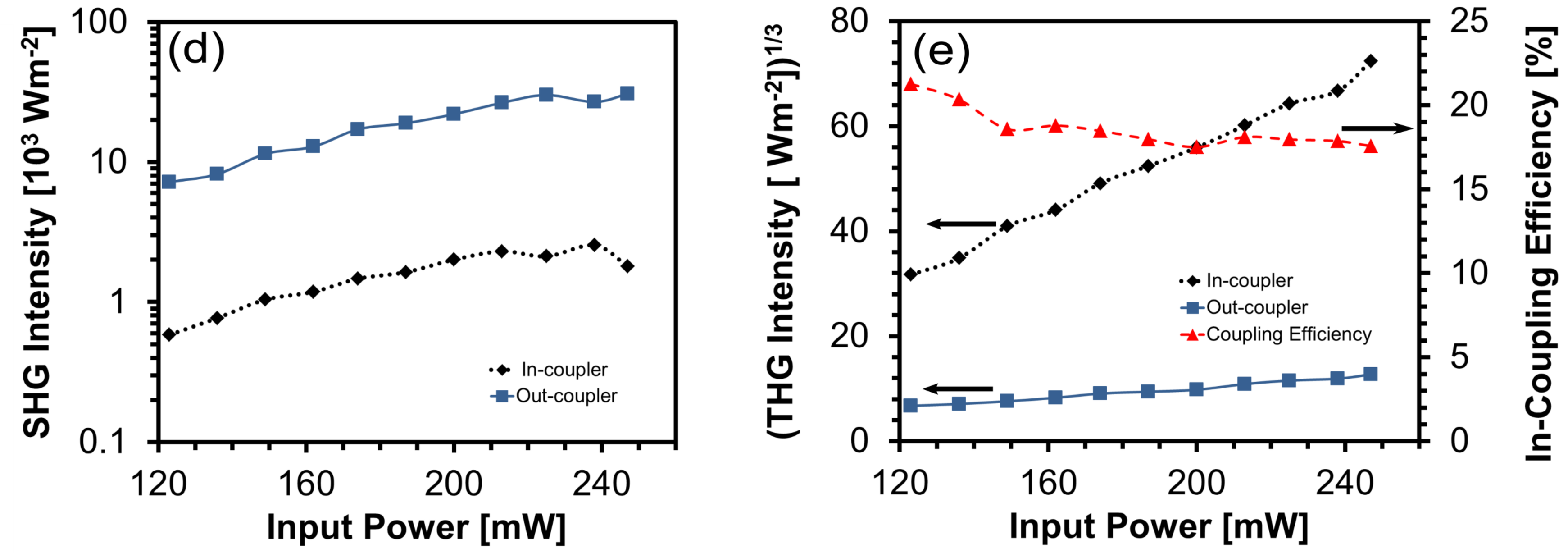


Figure 4: (a) Calculated pulse dispersion of the in-couplers as compared to 4μm of propagation in a SOI waveguide. Schematic for the SHG and THG measurements at the (b) in-coupler and (c) out-coupler. Comparison of the (d) SHG and (e) THG measurements.

Conclusion

The high coupling efficiency, low dispersion, and broadband coupling of the devices proposed in [1] have been confirmed experimentally, with in-coupling efficiencies as high as 21% at λ=1.5μm for a 330/225nm asymmetric particle pair separated by 300nm. The strong coupling nature was confirmed through nonlinear measurements of second harmonic and third harmonic generated signals. The essentially broadband nature was maintained despite the effects of the buried oxide layer.

ACKNOWLEDGEMENTS

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REFERENCES

[1] T. P. H. Sidiropoulos, S. A. Maier, and R. F. Oulton, “Efficient low dispersion compact plasmonic-photonic coupler,” Opt. Express **20**, 12360-5 (2012).