Coherent absorption at interfaces for film thickness measurement and plasmonic selective excitation

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We demonstrate using two coherent light beams to measure the thickness of absorptive thin films and selectively excite plasmonic resonances at the surface of transparent bulk substrates.

Surface plasmon resonance in metal nanostructures induces strong light absorption at the nanoscale. We have recently demonstrated modulating light absorption in an optical standing wave for optical data processing [1] and selective excitation spectroscopy applications [2]. However, these previous analyses and demonstrations have generally been limited to free-standing thin films and are not immediately applicable to samples residing on a thick substrate. Here we report coherent absorption of absorptive thin films and nanostructures at the surface of a transparent and thick substrate. This may lead to a variety of practical applications for coherent absorption.

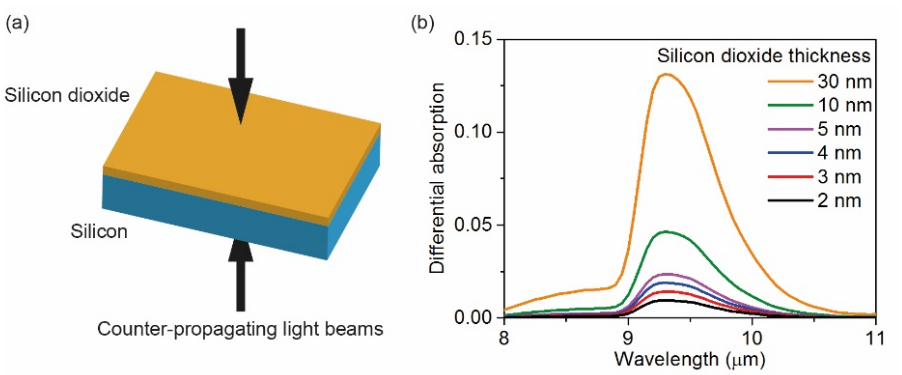

Figure 1. Coherent absorption for detecting the thickness of silicon dioxide at the surface of a silicon substrate. (1) Two counter-propagating light beams illuminate the sample at normal incident. The light absorption is modulated by adjusting the relative phase and intensity of the two beams. (2) The maximal coherent absorption is compared with the absorption under conventional, single-beam illumination. The difference highly depends on the thickness of the silicon dioxide layer, making coherent absorption a promising technique for thickness detection.

Figure 1 shows an example use of this technique: determining the thickness of a thin layer of silicon dioxide (SiO_2) on top of a silicon substrate, a very important parameter for many applications. In the mid-infrared regime, silicon dioxide is absorptive while silicon is transparent, providing an ideal platform for coherent detection. Figure 1b shows numerically simulated results of differential absorption in a standing wave and a single-beam travelling wave, a value that can be obtained relatively easily in experiment using a mechanical chopper. The differential absorption shows strong dependence on the thickness of SiO_2 even at a thickness of only a few nanometers.

We further investigated the selective excitation of plasmonic resonances in nanostructures on bulk glass substrates. Multi-layered nanostructures are designed to support intertwined electric and magnetic dipole resonances. Through numerical simulation, we demonstrated disentangling these resonances through coherent excitation.

References

[1] X. Fang, K. F. MacDonald & N. I. Zheludev, "Controlling light with light using coherent metadevices: all-optical transistor, summator and invertor," Light: Science & Applications 4, e292 (2015).
[2] X. Fang, M. L. Tseng, D. P. Tsai & N. I. Zheludev, "Coherent excitation-selective spectroscopy of multipole resonances," Physical Review Applied 5, 014010 (2016).