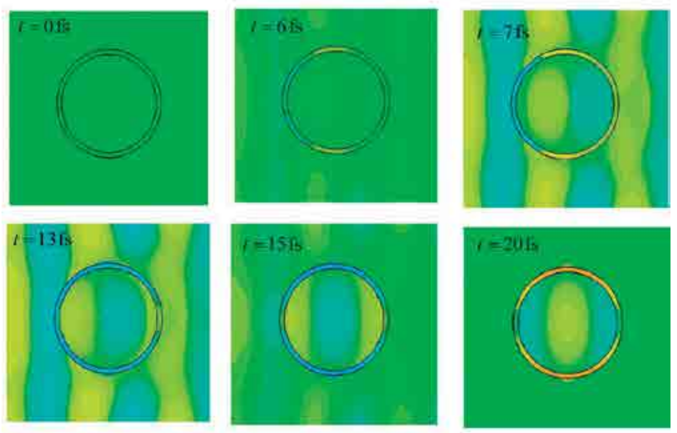
Trapping Light in Open Resonators

The capacity to localize light into a small region of space is of paramount importance in many areas of modern science. We developed a mechanism to store a quantized 'bit' of light—with a very precise amount of energy—in an open core-shell plasmonic structure with a nonlinear optical response. Notwithstanding the trapped light state is embedded in the radiation continuum, its lifetime is not limited by the radiation loss.



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Indicators	
Funding	39k €
Journal Papers	6
Conference Papers	7
Concluded MSc:	1
Two Main Publications	
S. Lannebère, M. G. Silveirinha, "Optical Meta-Atom For Localization Of Light With Quantized Energy", Nature Communications, 6, 8766, 2015.	
F. R. Prudêncio, J. R. Costa, C. A. Fernandes, N. Engheta, M. G. Silveirinha, Experimental Verification Of "Waveguide"-Plasmonics, (Under review)	

PROJECT WEBPAGE URL

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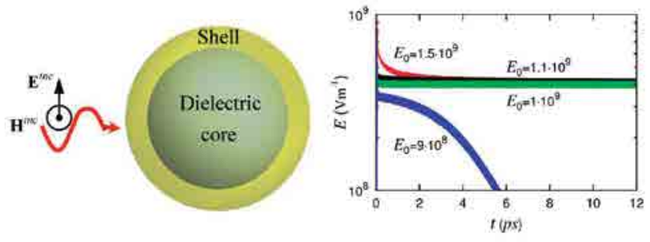

Fig. 1 (Left) Geometry of the Optical Meta-Atom and sketch of the incoming light pulse. (Right) Electric field in the core of the meta-atom as a function of time for different peak amplitudes (E_0) of the incoming wave. The duration of the incident pulse is only 16.3 fs. For a sufficiently large amplitude of the incoming wave a quantized amount of energy is held trapped within the meta-atom.

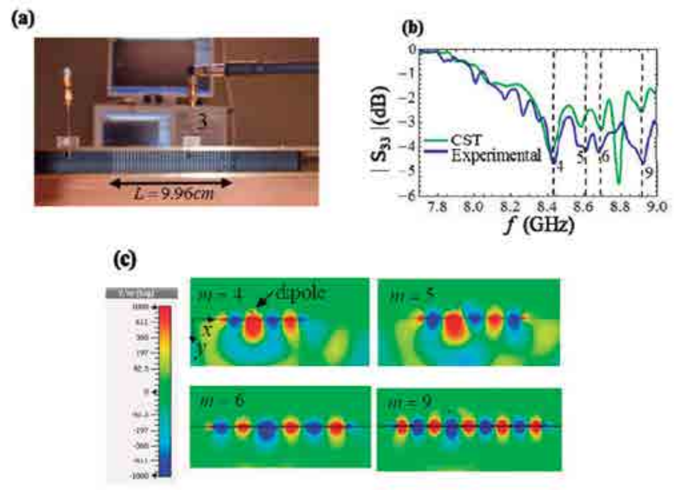

Fig. 2 a) Photo of the edge resonator prototype based on the concept of "waveguide"-plasmonics. b) Return Loss of the dipole antenna used to excite the edge resonator. The dips are associated with the resonator modes of different orders. c) Numerically simulated field profile (time snapshot) for each of the resonances of the return loss.

GENERAL MOTIVATION AND OBJECTIVES

The natural modes of oscillation of a physical system can be usually split into two categories: the bound modes – which form the discrete spectrum – and the extended modes – which form the continuous spectrum. Usually, the discrete and the continuous spectra do not overlap. For example, the allowed energy levels of the hydrogen atom are split into two disjoint subsets: the discrete negative energies (bound states) and the continuous positive energies (free-electron states). Having a spatially localized state in a spectral region where the modes are inherently delocalized is contrary to common sense. Surprisingly, it was shown by John von Neumann and Eugene Wigner in 1929 that bound states embedded in the continuum – technically known as embedded eigenstates – are really allowed within the framework of the usual wave theories.

CHALLENGE

The confinement of light into a small space region may enable a variety of breakthroughs such as all-optical memories. Therefore, it is interesting to extend the concept of "embedded eigenstate" to optics. Until recently all the known configurations to localize light in the radiation continuum with infinite lifetime required infinitely extended material structures. Indeed, light is an object difficult to tame. No matter how elaborate and intricate are the material constructions that may be used to screen it from the exterior environment, there is always some residual coupling with the radiation continuum, and hence light—if not absorbed by the material walls—always finds its way out.

WORK DESCRIPTION AND ACHIEVEMENTS

We introduced a novel approach to trap light in a bounded open cavity with suppressed radiation loss. Under some strict conditions, plasmons—that is, charge density waves in metals—may enable the formation of 'embedded eigenvalue' states in finite sized cavities. The light trapping can be attained with a two-layer spherical structure designated by 'meta-atom' (Fig. 1, left). The meta-atom shell is ideally formed by a plasmonic material with vanishing permittivity and the core is a regular dielectric. The trick to let the incoming light in the meta-atom but to not flee afterwards relies on a nonlinear effect that squeezes the light wavelength in the core until it reaches a critical value for which the light is perfectly screened by the plasmons. Furthermore, in the same manner as the energy levels of regular atoms are quantized, the amount of energy trapped in the meta-atom has a very precise value. The optical meta-atom can trap a light "bit" when illuminated by an incoming light pulse (Fig. 1, right), for a time limited only by the effects of material absorption. In practice, the loss effects can be compensated with a gain element similar to what is used in lasers. It is envisioned that with such a strategy the meta-atom may function as a basic one-bit optical memory. We partially validated some of the proposed ideas at microwave frequencies. Specifically, we designed, fabricated and tested an edge resonator formed by the interface of a waveguide region that behaves effectively as a regular dielectric with positive permittivity, and a waveguide region that emulates the response of a plasmonic material with negative permittivity. Interestingly, the proposed open resonator supports highly confined plasmonic-type resonances (Fig. 2). It is expected that this pioneering study may pave the way for a future demonstration of a fully operational 'meta-atom' at microwave frequencies.