optics & photonics focus

Rewinding Plasmons Back in Time

Day-to-day life common sense often does not apply in science. But sometimes it works better than any other approach. Scouts know that retracing back clear markers on the way can avoid getting lost, the same principle has been recently proved to work in nanoplasmonics.

Often, the task of controlling light in nanostructures looks like trying hard to get out of a labyrinth by chance. In Greek Mythology, Theseus employed a providential thread, provided by Ariadne, to wind his way back in the maze. Recently, Xiangting Li and Mark I. Stockman at Georgia State University (Atlanta) have discovered that plasmonic nanostructures provide the modern Theseus (ourselves) with a sort of Ariadne's thread: when excited in a spot, they emit a signal that can be rewound back in time to localize light at the same spot and find the way out from the plasmonic labyrinth.

Their research lies within the framework of light-to-matter interactions at the nanoscale, in particular of surface plasmons. Surface plasmons are resonance phenomena arising from the interaction between the light incident on a metal and the oscillation it induces in the metal free electrons. The light behaves like a child pushing a friend (the free electrons) on a swing: the swing will go higher and higher (maximum amplitude) only pushing in time with its natural oscillation (resonance frequency).

Surface plasmons have a great potential toward light confinement and control at the nanoscale: while confinement has been successively achieved, dynamic control is still elusive. Control at the nanoscale cannot be imposed by light focusing because the spatial resolution is limited by diffraction. Using focused light would be like bowling the ball down the alley to selectively knock down just one, and only one, specific skittle at a time. Not possible: the ball is simply too large!

In 2002 Stockman and coworkers proposed a new approach to ultrafast optical control at the nanoscale [1]. Resuming their idea, Stockman points out that "light cannot be focused at the nanoscale, but can carry additional information in its phase and polarization modulation, just as common radiowaves do in broadcasting." This information is the missing piece of the puzzle in order to help control light localization over plasmonic nanosystems. When this idea came to life, "many researchers were sceptical about its experimental feasibility because of technological limitations at the time, but," Stockman continues, "the first experiments were finally done and many others have followed."

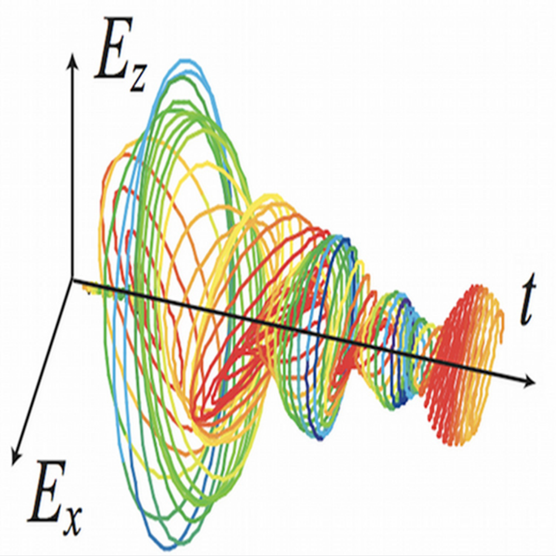

Figure 1: The plasmonic Ariadne's thread. Example of time signal generated by a plasmonic nanostructure following an external excitation. These signals reverted in time can be used to control light localization in the same nanostructure.

One of the most impressive experiments was carried out by M. Aeschlimann and coworkers in 2007 [2]: a learning algorithm modulates phase and polarization of light step-by-step until it achieves light confinement over the desired spot of a nanostructure. This trial-and-error method eventually hits the aforementioned skittle by employing a bullet (phase and polarization modulation of light) instead of a bowling ball (light focusing). Even so, we are not taking aim, but shooting almost randomly and each time adjusting our aim until finally we hit our target.

Recently, Li and Stockman have found the way to hit the target first time. In their approach, which at the moment is only theoretical, surface plasmon oscillations are excited over the desired spot of a nanostructure by an external source placed in its vicinity, for example by an oscillating dipole. The time evolution of the system during the excitation is recorded far away from the structure where many details are lost. What is astounding is that, in spite of everything, the time evolution of the recorded signal still preserves most information about the time evolution of the system. It is like receiving a noisy and fragmented phone call, but still being able to understand it because all the keywords are there. The time-reversed signal is used then to reload in the system the same response to the excitation source in a controlled way. “Our idea,” Stockman summarizes, “exploits the remarkable property of resonant plasmonic systems to retrace their own evolution back in time,” like Ariadne’s thread.

Apart from the intrinsic elegance of the approach, according to the authors, “wireless control of optoelectronic nanocircuits appears to be the main application currently foreseeable.” Thanks to their ultrafast kinetics and the possibility to manipulate light confinement, plasmonic nanostructures are suitable for various applications, ranging from ultrafast computations to data control and storage at the nanoscale, but “many others may follow that we cannot even imagine.”

“This new proposal is well substantiated by calculations, even though,” Javier García de Abajo from the Institute of Optics in Madrid (Spain) points out speaking about its experimental feasibility, “learning algorithms are more robust and overcome the technological problems connected to positioning an external source in the vicinity of the desired spot of a nanostructure.”

Stockman also admits that “there are significant technological problems to its experimental realization,” however, remembering his past experience and being confident about the future, he affirms that “if history is of any guidance, it may occur.”

[1] M. I. Stockman *et al.*, *Coherent Control of Femtosecond Energy Localization in Nanosystems*, Phys Rev Lett **88**, 067402 (2002).

[2] M. Aeschlimann *et al.*, *Adaptive subwavelength control of nano-optical fields*, Nature **446**, 301-304 (2007).

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X. Li and M. I. Stockman, **Highly efficient spatiotemporal coherent control in nanoplasmonics on a nanometer-femtosecond scale by time reversal**, Physical Reveview B (2008) **77**, 195109.