MARCOS DANTUS

LASER CONTROL OF CHEMICAL REACTIONS

Scientific and technological breakthroughs breathe renewed life into area of study

WHEN I STARTED CONTEMplating the laser control of chemical reactions as an undergraduate, the cost of laser-produced photons with sufficient energy to break chemical bonds was about $100,000 per mole. This staggering figure indicated that even if some control were possible, interest in this endeavor would be purely academic. Until then, most early experiments on mode-selective excitation had failed to achieve bond-specific chemistry. However, beginning in the early 1980s, several scientific and technological breakthroughs significantly improved the prospects for laser control of chemical reactions, making it one of the most promising areas of current research.

An ultrafast (10^{-14} seconds long) laser pulse can be used to excite molecules on a time scale shorter than vibrational motion; a second ultrafast pulse delayed in time can monitor the ensuing dynamics and cause the desired chemistry. This method is the optical version of a one-two punch. Because it depends on the natural dynamics of the molecules after each laser excitation, this approach is the basis for ultrafast studies of chemical reactions (for which the Nobel Prize in Chemistry was awarded in 1999).

The goal for laser control is to have the energy localize on the desired bond rather than dissipate throughout the molecule. This requires very specific phase information to be introduced in the laser pulse. To control dynamics in ground or excited states, one may need coherent combinations of phase- and amplitude-sculpted pulses that can take advantage of the constructive and destructive interference of the quantum mechanical wave function. Laser control, therefore, requires "smart" photons.

Producing smart photons requires ultrafast laser pulses, sophisticated pulse-shaping technology, and the coherent combination of several pulses, in phase or out of phase with each other, much like in multiple-pulse nuclear magnetic resonance. All of this technology is now available, which leads to the obvious question: What is the cost of a mole of smart photons (fittingly called an "einstein")? The development of diode lasers, regenerative amplification, and chirped-pulse amplification has resulted in incredibly efficient and powerful ultrafast laser systems. Such developments have brought the cost of a mole of photons with the requirements specified here to a level similar to the cost of a mole of an average reagent!

PULSATING **Dantus' lab is filled with femtosecond laser systems used to study ultrafast dynamics and control of chemical reactions.**

We are entering a new era in the field of laser control of chemical reactions. We understand the principles behind molecular energy dissipation, we know how to generate sophisticated laser pulses, and, for the first time, it makes financial sense to develop laser synthesis.

In our research group, work is proceeding along two lines. The more fundamental work focuses on laser-molecule interactions. We are exploring how to harness coherent, nonlinear, multiple-pulse methods to cause selective excitation. This work is aimed at studying the ultrafast energy dissipation that takes place in large molecules (such as N_2O_4) and learning how to arrest and perhaps reverse this process by using photon echo techniques. The methods being developed could be used to encode and manipulate information that is stored on quantum superpositions of states.

The more applied work is aimed at controlling chemical reactivity. One can envision selective bond fission in a molecule (a unimolecular process) or the reaction between two reagents (a bimolecular process). In principle, laser synthesis or laser catalysis could be used to produce unique products that defy conventional synthetic methods.

The role of lasers in most industrial applications is merely that of an energy source. Smart photons, from ultrafast shaped pulses, could revolutionize techniques such as laser machining, laser deposition, and laser desorption. We are presently working on matrix-assisted laser desorption and ionization (MALDI). This method is used to produce protein ions for analysis by using mass spectrometry. With optimized laser pulses, we plan to give the user the possibility of selecting which type of molecules ionize and controlling their fragmentation. The ultimate goal of this research is to produce an automated protein-sequencing apparatus.

I cannot imagine a more exciting time to be a scientist. In the field of laser control as well as in other fields, we are reaching the point where technology allows us to pursue many projects that were considered unthinkable 10 or 20 years ago.

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