Transcending limitations

Obtaining new insights into yet unexplained phenomena and making the impossible possible are among the main motivations for any scientist. Going beyond limitations is the key challenge.

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In September 2011, the European Organization for Nuclear Research (CERN) announced that OPERA, an experiment in Italy, had made the greatest discovery of the century: that neutrinos can travel 0.002% faster than light[1]. Unfortunately, in June 2012, this turned out to be a false signal caused by a bad electrical contact[2]. This unconventional and scientifically Earth-shattering result stimulated the imaginations of researchers to consider a world with velocities exceeding that of light.

In photonics, there are many topics associated with breakthroughs in the 'conventional' features of light, such as focusing beyond the diffraction limit, ultrashort pulses on the attosecond timescale[3], high energy-conversion efficiencies for photovoltaic devices, and high-temperature operation of terahertz quantum cascade lasers[4].

In general, there are two types of limitations. The first is a technological limitation. For example, the ability to observe motion in a biological sample is widely desired throughout biophotonics. An electron microscope possesses a much higher spatial resolution than an optical microscope. Unfortunately, electron beam irradiation can damage living tissue. Furthermore, these studies must often be performed in vacuum, and few biological samples can survive in such an environment. For these reasons, scientists desire an imaging scheme that can provide sequential images at high frame rates and at resolutions beyond the diffraction limit of light — a technique now described by Y. Cotte *et al.* in this issue[5]. Cotte *et al.* have developed a digital holographic optical microscope with a lateral resolution below 100 nm by using a diode laser emitting at 405 nm. The vivid motion of a synaptic network can be seen in their Supplementary Information video files.

The second type of limitation is conceptual; that is, the finding of unprecedented phenomena. As an example, the work by P. Vasa *et al.* reported in this issue presents the real-time observation of ultrafast Rabi oscillation between excitons and plasmons[6]. Although many reports have suggested strong coupling between excitons and plasmons, these were only conjecture. No one yet knows how to control the ultrafast energy transfer between excitons and plasmons at will. Elucidating the mechanism of the strong coupling is therefore significant in terms of both fundamental understanding and technological applications.

Arguably, a conceptual breakthrough generates more debatable questions than a technological breakthrough because there are fewer common factors to compare with other relevant works. In such cases, the advantages introduced by an original idea or a new finding can include one of the criteria for the conceptual breakthrough. In the case of the work by Vasa *et al.*[6], demonstrating the control of the Rabi frequency by light-induced exciton population is an intriguing novel phenomenon in terms of fundamental physics. It should be noted their work entails scalability and ultrafast energy transfer on timescales of around 10 fs — both of which are highly desired by researchers exploiting active all-optical nanophotonic circuits and devices.

Some say that state-of-the-art experimental equipment is imperative for transcending limitations. In a sense, that is true. For example, without photon detectors capable of detecting ultraweak intensities, it would be impossible to investigate optical phenomena at the quantum noise level. However, one might ask if experimental equipment alone is a sufficient condition to achieve breakthrough — the answer is clearly no. As all researchers know, the outcome of a study may not be the outcome expected, even when state-of-the-art equipment is used. To overcome unexpected difficulties or problems, vision and strong will are equally important.

Susumu Noda, who in this issue reports a waveguide structure in a three-dimensional photonic crystal[7], recalls the difficult times in the early days of his research: "People around me said it was impossible to fabricate three-dimensional photonic crystals for near-infrared light because it requires nanometre-scale fabrication accuracy. However, I customized the equipment in my laboratory and developed fabrication techniques step by step. When I tried to investigate three-dimensional photonic crystals, most of the results were unexplainable, probably because of structural imperfections. I scrutinized these data and sorted out the technical issues." He stressed that the difficulty of transcending limitations is to find a solution that has never been found before. "It should be remembered that steady progress will eventually make a leap that overcomes a great difficulty," said Noda.

The research published in *Nature Photonics* provides a glimpse into how researchers have tried to overcome technical difficulties or obtain further insights in science. Perhaps some of the research in this issue will inspire you, the reader, to imagine a world beyond limitations? ❐

References

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