Femtophotography

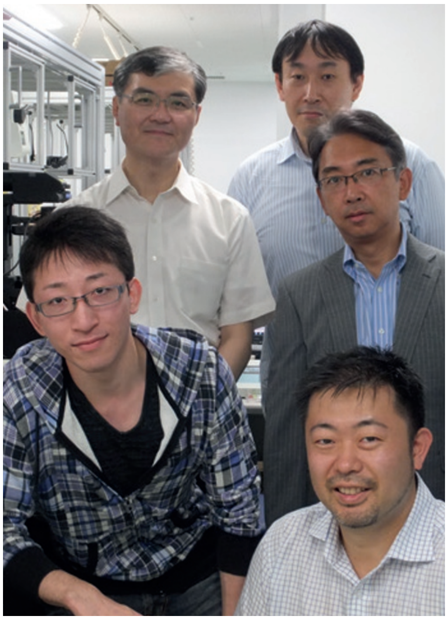
A burst-mode camera developed in Japan called STAMP with a femtosecond frame rate could become a powerful tool for studying ultrafast dynamics. *Nature Photonics* asked Keiichi Nakagawa about the technique.

How did this ultrafast camera come about?

From the very start of my research, I have been interested in the interaction between living cells and acoustic shock waves. It is believed that mechanical stress may be linked to curious biological phenomena such as increases in bone growth, angiogenesis and other effects. However, more research is needed to fully understand what is happening. In terms of biology, nobody really knows what is actually happening inside a living cell after it is exposed to an acoustic shock wave. I came to the conclusion that a means of observing fast, transient phenomena must be developed to better understand the problem. Thus, I was looking for an experimental technique for making observations on timescales faster than a nanosecond. I listened to a talk on high-speed photography by Keisuke Goda (who was at UCLA at that time) and thought that his scheme called serial time-encoded amplified microscopy (STEAM) might be suitable. However, I quickly realized that STEAM wouldn't work because it is not fast enough. It is totally different from what I was searching for. I needed a camera that captures an image with much finer time resolution. So, I decided to construct an image capture system that did exactly that. To this end, I approached a number of the experts inside and outside of the University of Tokyo and ultimately we developed our technique called sequentially timed all-optical mapping photography (STAMP).

What was the most difficult aspect of developing the camera?

We built the experimental equipment as planned, but it turned out to be much harder than anticipated to actually capture an image. STAMP is implemented using a burst-mode camera, which requires synchronization with a triggered event. So, we had been wondering for several months if problem was that the synchronization was off, or if a high-speed phenomenon was perhaps being induced. During this time, Keisuke Goda moved from UCLA to the University of Tokyo and joined our research, which was very helpful as he was able to provide us with very useful advice for optimizing STAMP. Finally, one day we managed to capture six consecutive images and there were screams of delight in the laboratory. That said, the quality of these initial images of lattice vibrational waves in a $LiNbO_3$ crystal was quite poor, with low contrast and blurring. In response to this, one of the members of the team, Ryoichi Horisaki, developed noise removal software to obtain clearer images and his software enabled us to fine-tune the optical alignment of STAMP. Finally, we achieved much better image quality, as shown in our paper.



Keiichi Nakagawa and colleagues have captured motion pictures of plasma dynamics and lattice vibrational waves using STAMP. Left, from top to bottom: Ichiro Sakuma and Keiichi Nakagawa. Right, from top to bottom: Atsushi Iwasaki, Fumihiko Kannari and Keisuke Goda. Image courtesy of Noriaki Horiuchi.

Can the performance of STAMP be pushed further?

There are two main opportunities for improving performance. The first is by speeding up the frame interval. Actually, a frame interval time on the order of femtoseconds is easily accessible by using a short glass rod as a pulse stretcher in the temporal mapping device. Although we wanted to show motion pictures on the shortest frame interval time possible to demonstrate the superiority of STAMP, we were not able to find suitable subjects that show macroscopic dynamic behaviour on such a timescale. We tried to capture the dynamic behaviour of lattice vibrational waves in a $LiNbO_3$ crystal with a frame interval of a few femtoseconds. Unfortunately, the frame interval was so short that there was no change in consecutive motion pictures. So, we purposely increased the interval to 229 femtoseconds. The second opportunity for improving the technique comes from increasing the number of motion pictures that can be captured. We are now developing a novel device that allows us to capture on the order of 100 motion pictures.

What future plans do you have for this research?

I still possess enthusiasm for the study of how acoustic shock waves affect living cells. I expect that high-speed motion pictures captured at unprecedented frame interval times using STAMP can offer fresh insights in biology. Beyond that, I'm getting interested in the study of dynamic behaviour on the atomic scale. So far we have used ultrashort laser pulses with wavelengths of around 800 nm, however the same scheme should work well for other wavelength ranges. For example, if STAMP can be configured for use with an X-ray or electron beam, we could realize a camera with unprecedented high resolution in both time and space. Given current research trends, it seems to me that there is a lot of interest in studying non-repetitive phenomena and STAMP is well suited to that.

INTERVIEW BY NORIAKI HORIUCHI

Keiichi Nakagawa and co-workers have a Letter describing their ultrafast imaging technique on page 695 of this issue.