Clive Siviour

Key words
photography
pixels
memory
resolution

Freezing the moment
High speed photography

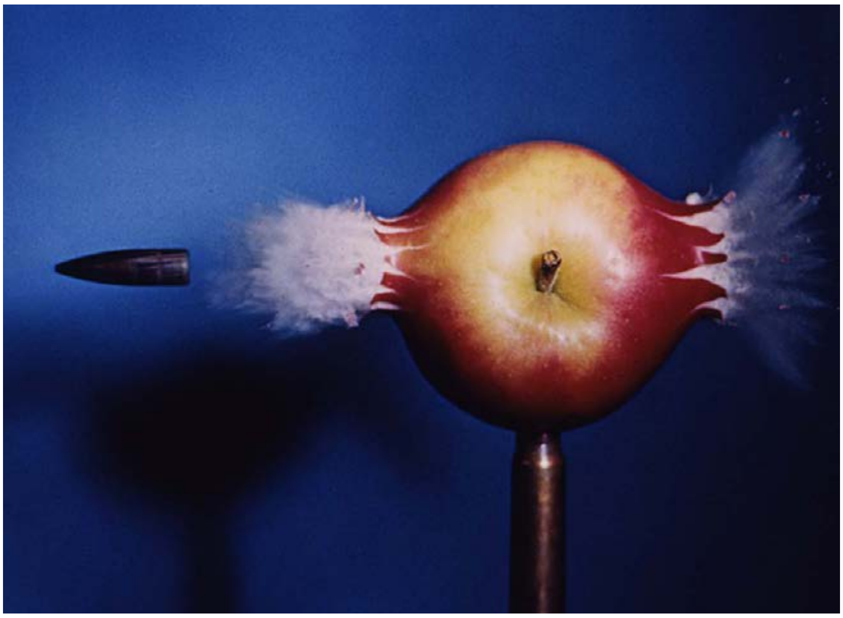
Many of us use photography to keep memories of an event: a holiday, a wedding or a party. This is also true in science and industry. But what if we need to understand a process that happens very quickly?

High speed photography allows us to freeze rapid events and extract direct visual information. In this article, we will explore the technology that allows us to take pictures at speeds up to 300 *million* pictures per second, and how this technology is used by scientists and engineers.

Milliseconds, microseconds

Many phones can record video at speeds of up to 60 frames per second. If you play this video back more slowly, you can often see movement that could not be observed with the naked eye. Just as a microscope allows us to see smaller objects, high speed photography allows us to see shorter times. A normal video sees down to about 0.1 s, but in industry, events might last 1 millisecond (ms) or even 1 microsecond (μs). Something faster is required.

A simple way to freeze a very rapid event is to use a short flash. The light from a typical flash lasts 1 or 2 ms, but, by discharging a capacitor rapidly across a small gap, it is possible to produce bright sparks lasting 1 μs or less. This allows us to take single pictures such as the bullet. Taking a sequence of images requires more expense and sophistication. It is necessary to process a lot of information very quickly. Here will will see the methods used by three types of modern digital cameras.



A bullet penetrating an apple at 840 m/s, an image taken in 1963 using a sub-microsecond flash by Harold Egerton. Egerton (1903-1990) was a pioneer of high speed photography; he worked at MIT.

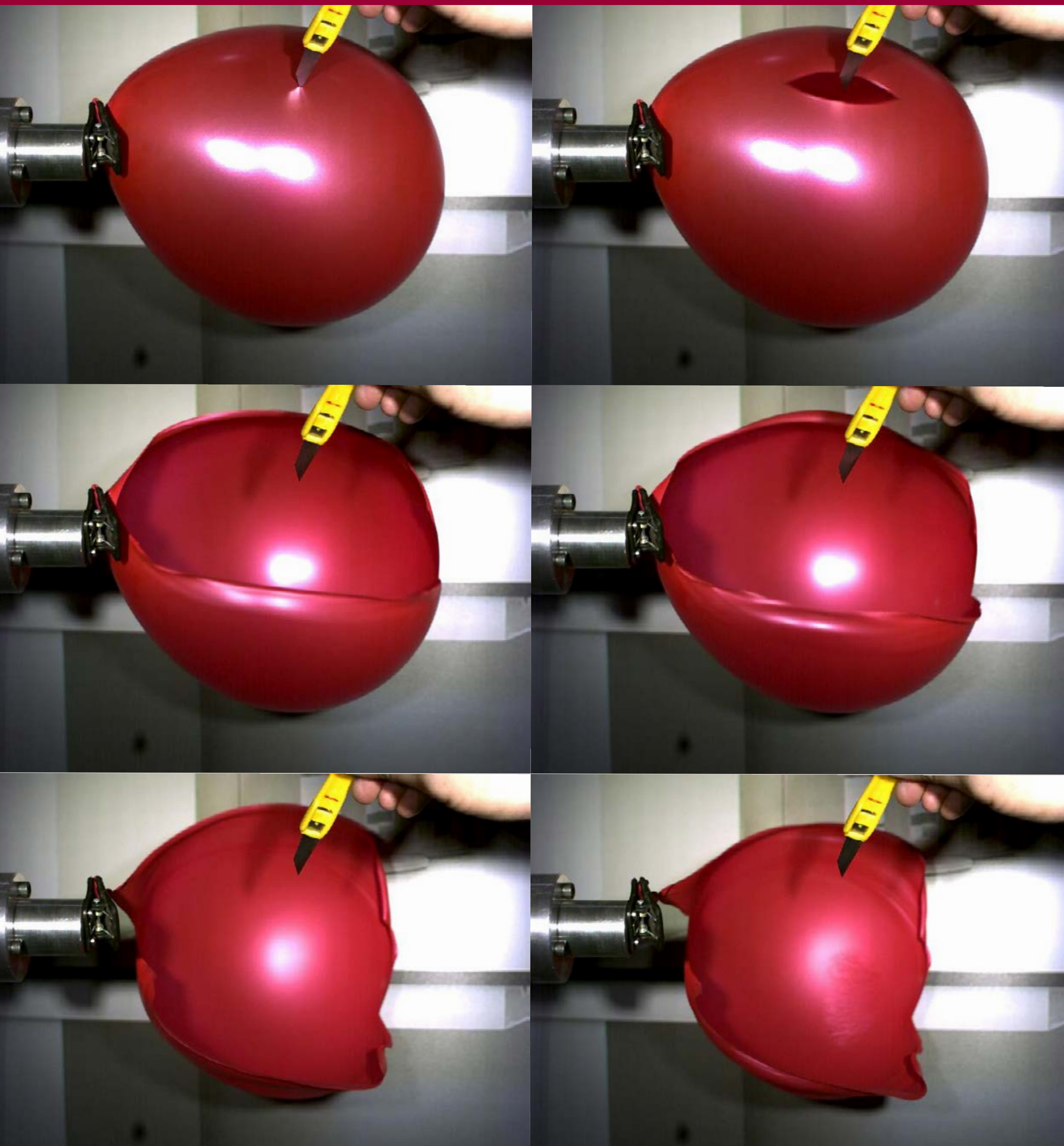
More sensors

To go very fast, the solution is to have not one sensor but multiple sensors. The incoming light is divided by a beam-splitter to illuminate all the sensors at once. The camera's electronics are programmed to activate each sensor in turn, which can be done *very* quickly. These cameras are capable of taking pictures at speeds of 300 *million* frames per second. Light moves only 1 m between images at this speed! However, typical cameras only have 16 sensors: only 16 images can be obtained at this speed.

Numbers large and small

1 millisecond is a thousandth of a second or 0.001 seconds; 1 microsecond is a millionth of a second, 0.000 001 seconds.

1 gigapixel is 1 billion (10^9) pixels; 1 terapixel is one trillion (10^{12}) pixels.



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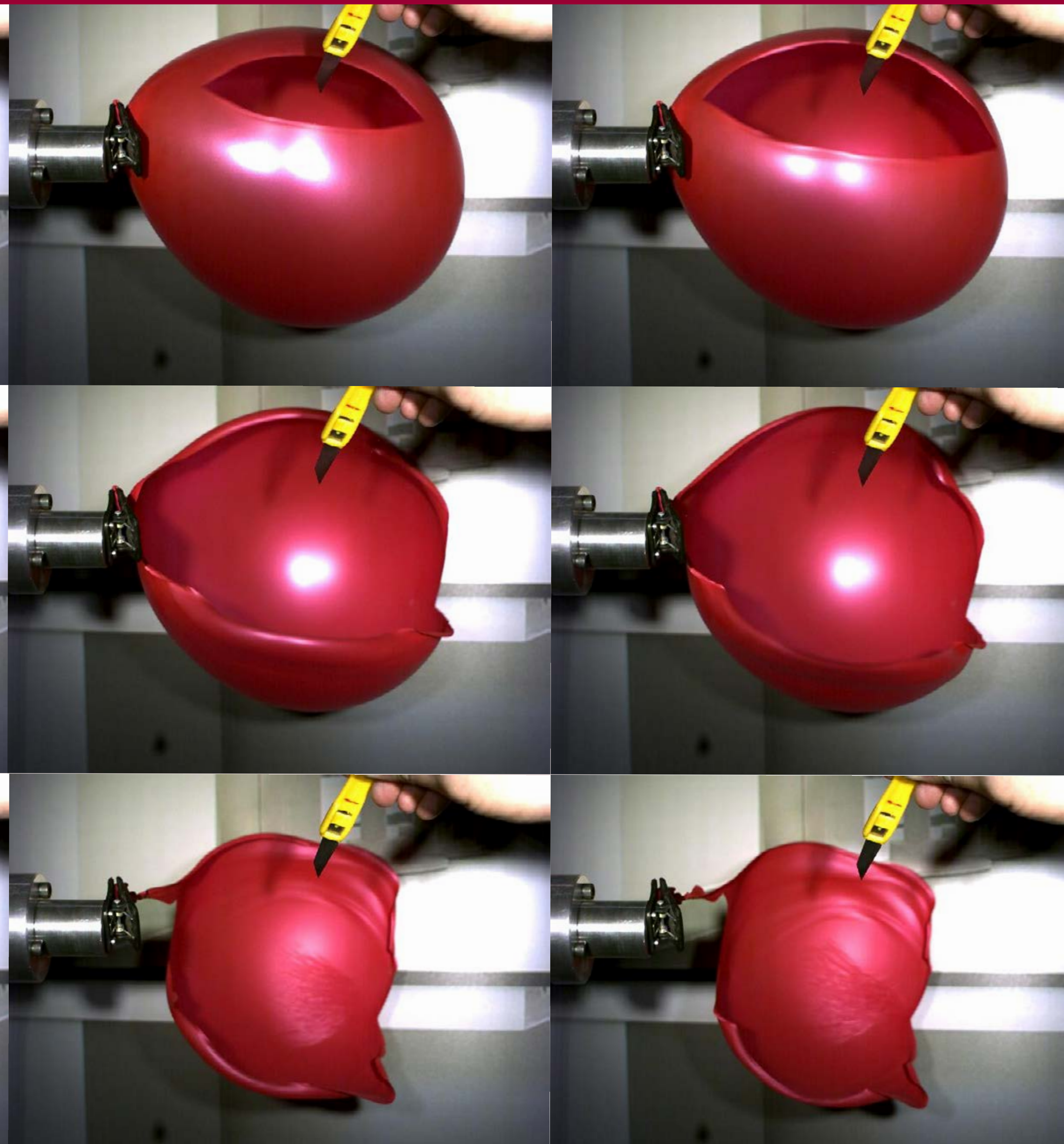
A balloon bursts – a linear crack extends as the tension in the rubber pulls the balloon open. Consecutive images are 0.40 ms apart.



The balloon bursts

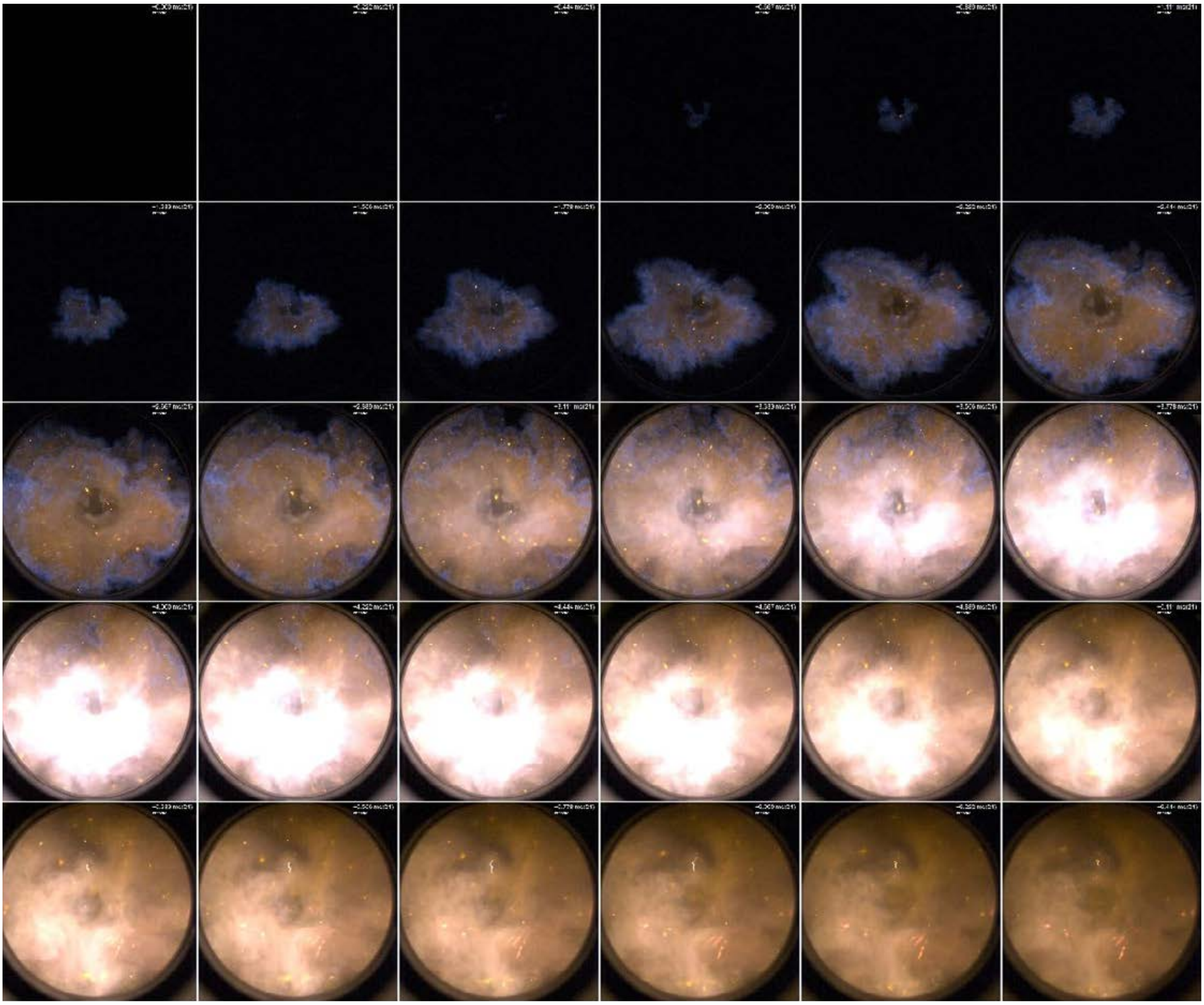
The sequence of images on pages 10-11 shows the bursting of an inflated balloon. The images were taken at 25 000 frames per second using a Photron Fastcam SA-X2. The resolution of each image is 768×576 pixels. We have selected every tenth image in the sequence so that the time interval between images is 0.40 ms. The speed at which the crack grows is determined by the material properties of the rubber combined with the pressure of the air inside the balloon.

A Photron Fastcam SA-X2 high-speed camera

More speed, less resolution

For many applications in industry, film and television, a high speed system similar to a normal video camera may be used. CMOS sensors (those in a standard digital camera) allow rapid data readout, and large pixels of 20 μm or more make the camera very sensitive to light. The data from the sensor must be transferred quickly to external memory. Even with modern electronics and sophisticated sensor design, the maximum readout speed of the camera is about 21 gigapixels per second, limiting the speed of a 1 megapixel image (1024×1024 pixels) to about 20 000 frames per second. To go faster, the image must be made smaller: the resolution decreases with increasing speed. Rates of up to 1 million frames per second are possible, and the duration of the video is limited only by the amount of memory in the camera.

Combustion of ethanol in air. Images taken at 9000 frames per second. Image courtesy of Tim Nicholls, Photron. ▼



On-sensor storage

A solution to the data processing is to store the images *on* the sensor and read them later on. One method to do this is for each pixel to contain an active light sensitive element, the imaging element, accompanied by storage elements. A picture is taken using the imaging elements, and then moved rapidly to the storage elements, so that the imaging elements can be used again. This happens at a rate of 3.5 terapixels per second. Once all the storage elements are filled, the camera can read out the data at a slower speed. Cameras using this technology can curently take images at speeds of 1–5 million frames per second with much higher resolution than high speed video, but are currently limited to a sequence of between 150 and 200 pictures.

Look here!

Further details about the cameras used and more high speed images:

Photron: *www.photron.com*

Specialised Imaging: *specialised-imaging.com*

High speed studies

High speed cameras are used extensively in industry and research. Applications include automotive safety and crash testing, ballistics and armour, studies of combustion in engines or industrial processes such as welding, and slow motion photography for film and television. Another important application is the study of biomechanics. Very high speed imaging is required for studies of explosives, for example those used in mining, or dynamic failure of materials such as ceramics and glasses. In my laboratory, we use high speed imaging to understand how materials and structures deform under impact loading, aiding the production of safer cars and aircraft.

Clive Siviour is Associate Professor in Engineering at the University of Oxford. His research interests include the behaviour of materials and structures when they are deformed very rapidly in impacts at speeds up to hundreds of metres per second.

High speed sequence showing inflation of a car's airbag. Images taken at 6000 frames per second. Image courtesy of Tim Nicholls, Photron. ▼