ChemSumer

The Chemistry of Digital Photography and Printing

Once upon a time, people put stuff called film in the their cameras. First, they paid for it. Then they took photos, but couldn't preview them on a screen. No deleting, no computer editing—they paid strangers to develop every miserable photo, hoping that a few were OK! So primitive! So last-century!

By Brian Rohrig

Imagine needing eight hours to take a single photograph! That's how long it took French scientist and inventor Joseph Niepce to take the world's first photograph in 1826. And the end result didn't win any prizes—it was a grainy image of some buildings viewed from a third-floor window. We have come a long way since then! Today, any amateur photographer can produce a glossy full-color photo in a matter of minutes using a digital camera and computer. In just the past 10 years, digital photography has taken the world by storm, threatening to do to film what the DVD has done to video.

The world's first photograph!

Most of your family photos were probably taken the old-fashioned way, with film that had to be taken to a photo shop to be developed. There is a fascinating bunch of chemistry involved in this process. All photographic film is coated with a thin layer of a silver halide compound, such as silver bromide (AgBr). When light strikes this layer, an image is recorded on film, which is made visible during the developing process. If you have ever been inside a darkroom, you have probably seen all sorts of mysterious chemicals such as developers, fixers, and baths. Even if you don't quite know how it all works, you can still appreciate the fact that a lot of chemistry goes into developing pictures.

Does digital processing mark the end of chemistry in photography? There is actually plenty of fascinating chemistry going on—it's just on a much smaller scale.

Sensing light

All cameras work by focusing light through lenses to create an image. A conventional camera records this image on film. A digital camera records this image on a permanent part of the camera known as a sensor. A typical sensor in a digital camera measures only 4.4 mm × 6.6 mm. This is about the size of a fingernail.

GETTY IMAGES

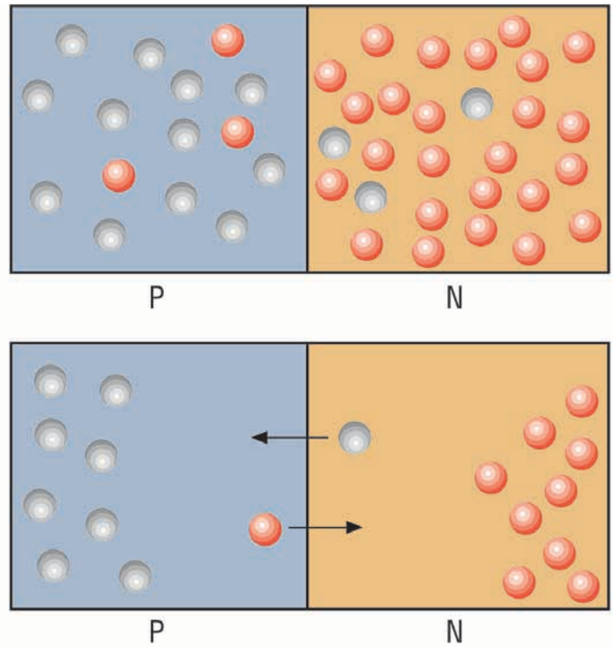
Sensor technology has enabled manufacturers to make digital cameras so small they can even be incorporated into cell phones. Similar sensor devices are used in fax machines, scanners, copy machines, and bar code readers at the grocery checkout.

The sensor is a semiconductor. Silicon is the material of choice for most semiconductors. This is ironic because silicon barely conducts electricity at all in its pure form. But if a small amount of impurity is added, through a process known as doping, then silicon becomes a fair conductor of electricity.

The sensor in a digital camera comprises many tiny semiconductors known as diodes. Diodes allow current to flow in one direction, but not another. Diodes are composed of two different types of doped silicon layers sandwiched together. One type of silicon is doped with phosphorus or arsenic. Both of these elements contain five valence electrons. Because silicon atoms only have four valence electrons, the doping agents provide the extra electrons that move throughout the material. With its excess of electrons, this type of silicon is known as *n*-type, with the "*n*" referring to the negative charge resulting from the free electrons.

Another type of silicon is doped with either boron or gallium, which only have three valence electrons. These doping agents create a deficiency of electrons in the structure, since silicon atoms have four valence electrons. This electron deficiency creates electron "holes" in the structure. Silicon doped with these deficient atoms is referred to as *p*-type silicon, with the "*p*" standing for the positive charge resulting from the deficiency of electrons.

When placed together, these two types of silicon form a diode, the one-directional conductor described above. Think of a diode as a one-way street for electrons. At the p-n junction, a positive charge builds on the n side, and a negative charge on the p side until the internal electric field counteracts the tendency of the electrons to fill the holes. The internal electric field then permits current to pass in one direction.



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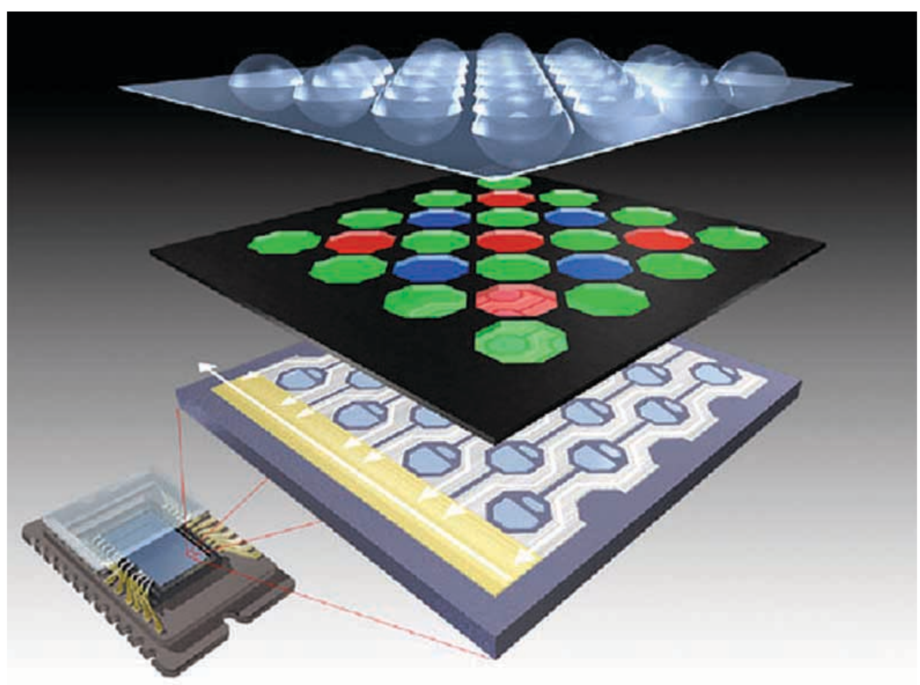
As more and more holes are filled with electrons, a region, neither P nor N, forms, called the depletion zone. Holes are shown as . Electrons are shown as .

Photosites

Each diode in a sensor is a *photosite*. Each photosite represents one picture element—better known as a pixel. The greater



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SuperCCD SR structure diagram, one microlens, one color filter, two photodiodes per photosite.

the number of pixels, the greater the resolution and overall quality of the pictures you take. For example, a typical digital camera may have a resolution of 640 × 480 pixels, for a total resolution of 307,200 pixels. The best digital cameras on the market today have a resolution of more than 10 million pixels (10 megapixels). For comparison, you should take pride in your personal sensor. The human eye contains 120 million pixels!

The pixels of any photo can be clearly seen through the low power of a microscope. The larger the pixel size in a photo, the poorer the quality, as larger pixels mean fewer pixels within a certain area. If you compare a normal color photo with a newspaper photo, you can see a huge difference in pixel size. Newspaper photos will have larger pixels, representing poorer quality.

When you take a picture with a digital camera, each tiny photosite on the sensor is exposed to light. When a photon is absorbed by the semiconductor, it promotes an electron to a higher energy level. What this means is that the high-energy electron acts like an electron that was added by doping: It is free to move about the semiconductor. Normally, the electron would just relax back to its lower-energy state. However, if it is near the *p-n* junction, it is attracted to the positive side, and migrates there, where it is collected.

As more photons strike a photosite, more electrons are knocked free. The greater the intensity of the light that strikes a photosite, the more electrons accumulate. A useful analogy is to think of the photosite as a tree, the photons as balls that you throw into the tree, and the electrons as leaves on the tree. Suppose that every time you throw a ball into a tree, a leaf is knocked loose. The more balls that you throw into the tree, the more leaves will accumulate on the ground below. A photosite that has been exposed to very bright light will contain far more electrons than one that has been exposed to dimmer light. Generally, each image sensor can record 256 different shades of gray, ranging from pure white to pure black.

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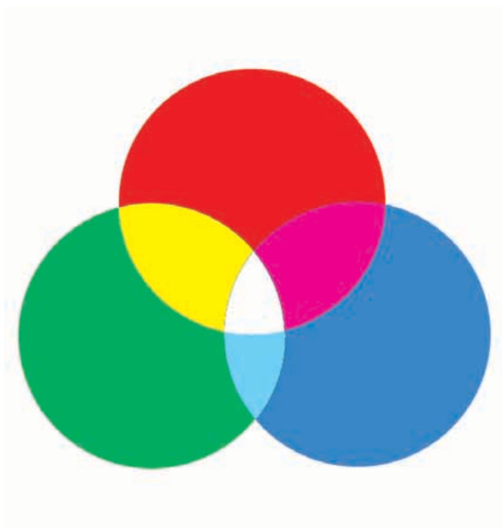
Information from photosites is converted to digital form and stored on memory cards for later retrieval.



Seeing in color

So then, how do digital cameras take color photos, if the sensors can only record shades of gray? The trick is to use filters, that combine to produce any color imaginable. Most cameras use the 3-color system to produce color. The three primary light colors are red, green, and blue. Together, these three colors make white. Any other color can be produced by mixing together various shades of these three colors. To accomplish this feat, either a red, blue, or green filter is placed over each photosite on the sensor of a camera. The most common pattern is known as the Bayer pattern, which alternates a row of red and green filters with a row of blue and green filters. This configuration gives you twice as many green filters as blue or red. Because the human eye is not sensitive to all three colors equally, extra green filters must be used to produce the best color for our eyes.

Next, the information at each of these photosites is converted to digital form. By themselves, electrons that accumulate at each photosite do not represent digital information that can be read by your computer. So every digital camera carries its own built-in computer that converts information to digital form and stores it on your memory card.

Printing

Once an image is recorded digitally by a camera and downloaded onto a computer, it can be printed. Or, it can be manipulated using software on a computer and then printed. The ability to choose, alter, and crop photos on screen before printing gives even a casual photographer unprecedented power to print only the images they want.

There are two basic types of printers that can print photos: laser and inkjet. The laser printer works by using static electricity. The underlying principle involves positively charged toner sticking to negatively charged paper, since opposite charges attract. A laser

beam projects a negatively charged image of whatever is to be printed onto the light-sensitive drum. The drum is then coated with positively charged toner, which is attracted to the negatively charged image on the drum. An analogy would be writing a message on the outside of a coffee can with glue, and then rolling it in flour. The flour will stick to the glue but not to the "unglued" parts of the can.

A piece of paper then passes over a charged roller, giving it an even stronger negative charge than the drum. The drum then rolls over the sheet of paper. The strongly negatively charged piece of paper pulls off the positive toner from the drum. Finally, the paper passes through a pair of heated rollers known as the *fuser*, which fuses the toner to the paper. After the paper attracts the toner from the drum, a discharge lamp bathes the drum in bright light, erasing the original electrical image.

Color printers work the same way, except the above process is repeated four times. Four types of toner are used: cyan (bluish), magenta (reddish), yellow, and black. By combining tiny dots of these four colors, nearly every other color can be created.

A photocopier works according to the same basic principle, except the electrostatic image that forms on the drum is formed by bright light that reflects off the paper to be copied. The drum is manufactured with a photoconductive material on its surface that makes it sensitive to light. White areas of the paper are reflected onto the drum. The black ink on the paper to be copied absorbs light, so parts of the drum do not receive an electrical charge. These uncharged parts of the drum will form the photocopy. Just like in a laser printer, the negatively charged toner is attracted to the positively charged image imprinted by light on the drum. A strongly positively charged piece of paper then attracts the toner from the drum. Your copy is complete once it passes through the heated rollers of the fuser.

Inkjet printers, as the name implies, work by spraying tiny droplets of ink onto the surface of the paper. Each drop is very tiny, being only about 50–60 micrometers in diameter. A micrometer (μm) is a thousandth of a millimeter. A human hair has a diameter of about 70 μm. There are two main types of inkjet printers on the market today. Bubble jet printers use heat to vaporize ink to form a bubble. This expanding bubble forces some of the ink onto the paper.

Inkjet printers work by spraying tiny droplets in ink on the surface of the paper and tend to produce better quality photos.

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When the bubble pops, a vacuum is created, causing more ink to flow from the cartridge into the print head. A piezoelectric printer works using piezo crystals (such as quartz). Piezoelectric crystals generate an electric field when distorted, but conversely, they can be distorted by an electric field. Thus, to get the nozzle to deform and eject the ink, an electric field is applied. This electric charge causes the nozzle to vibrate, forcing ink out on the paper.

Digital photos can be printed using either laser or inkjet printers, but inkjet printers tend to produce better quality photos. An inkjet photo printer will generally use six colors as opposed to the four that are normally employed in a color printer. Other types of photo printers use a dye sublimation technique. Sublimation is the process of changing phase from a solid to a gas, skipping the liquid phase altogether. Heat is used to vaporize solid dyes, which permeate the paper before they return to the solid form. Thermal autochrome photo printers require the use of special paper that already contains the ink. A print head delivers various amounts of heat to the paper, causing various pigments to appear.

Amazingly, experts agree that digital photography is still in its infancy. We will no doubt see huge advances in digital quality and convenience in the near future. Will digital cameras completely replace conventional cameras? There are photographers who remain devoted to the artistic and visual effects of developed film and darkroom processing. For most of us, it's nice to know we have plenty of options available for recording lasting images of our big moments. And it's all due to—you guessed it—chemistry!

Brian Rohrig teaches chemistry at Jonathan Alder High School in Plain City, OH. His most recent *ChemMatters* article "There's Chemistry in Golf Balls" appeared in the October 2005 issue.