Michelle Moram

LEDs lighting up a brighter future!

Like food, water, clothing and shelter, light is essential to our lives and is needed by most people for most of their waking hours. Michelle Moram of Cambridge University describes the latest, energy-efficient lighting technologies.

Currently, about 20% of our electricity supply is used for lighting, but scientists and engineers hope to reduce this amount by developing more efficient ways of generating light. This is important because electricity generation is currently the single biggest source of man-made carbon dioxide emissions: at the moment, the energy used in lighting is enough to power all the world's aircraft three times over!

What's wrong with the light we've already got?

Right now, many people still use the old-fashioned incandescent bulb, which was invented by Thomas Edison in 1879. This works by passing an electric current through a very thin tungsten wire, which then gets so hot that it glows – around 3200 °C! Unfortunately, about 95% of the electrical energy that goes into the light bulb is wasted as heat, whereas only 5% is converted into light.

A more modern option is the fluorescent lamp, invented in the 1970s. This works by filling a tube with mercury vapour and passing an electrical current across it, generating ultraviolet (UV) light. This UV light is then converted to white light by a special fluorescent coating on the inside of the lamp. However, even the best fluorescent lamps waste about 80% of the electrical energy that is put into them. What's more, many people don't like the light they produce, which flickers and which tends to make colours look different to the way they look in daylight. Also, they are not always as reliable as the manufacturers claim!

Box 1 on page 18 describes how the eye responds to light of different colours.

What are the alternatives?

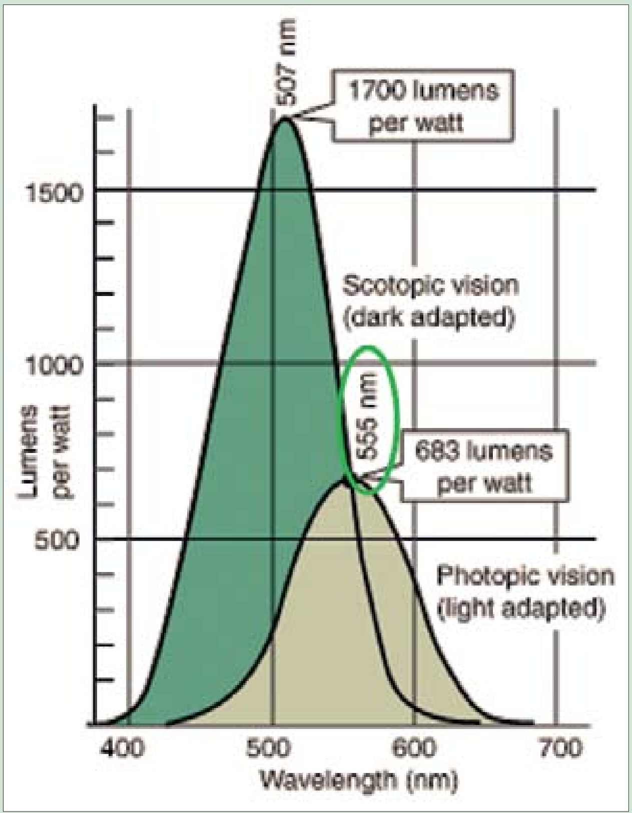
Many different technologies have been proposed as replacements, such as organic polymer light emitting panels, halogen lamps and semiconductor light-emitting diodes (LEDs). However, out of all of these options, LEDs are emerging as the most promising.

This torch has 12 white LEDs instead of a single incandescent bulb.

Railway signals are increasingly being converted to use LEDs because they are brighter than conventional lamps, cheaper to run and require less maintenance.

Key words
lighting
efficiency
light-emitting diode
semiconductor

Box 1



The sensitivity of our eyes to light of different wavelegths under bright daylight conditions (photopic vision) and moonlight conditions (scotopic vision)

What you see is what you get – or is it?

The efficiency of a light source is simply defined as the ratio of the light output power to the electrical input power. Simple, right? Actually, the efficiency isn't really a fair measure of how good a light source is, because we can't see all colours equally well. In fact, our eyes detect green light far better than they detect red or blue light. This is why night vision goggles, radar screens and other equipment that might be operated in the dark usually have bright green screens or displays.

A green night vision device display

To account for the differences in our ability to detect light of different colours, we usually measure light output in lumens, which are an indicator of how much light we can actually see. Now we have a better way of defining how good a light source is – its luminous efficacy, which tells us how much useful light in lumens (lm) is produced per watt (W) of electrical input power. A green light of wavelength 555 nm has the maximum possible luminous efficacy of 683 lm/W, but in order to make white light, we are obliged to add some red and some blue light as well, which our eyes can't detect so well. This means that white light sources will always have lower luminous efficacies, reaching a theoretical maximum of around 240 lm/W. The world record for white LEDs currently stands at 186 lm/W. When we compare this to fluorescent lamps (60 lm/W), ordinary incandescent light bulbs (12 lm/W) and oil lamps (0.1 lm/W), it is easy to see just how much potential LEDs have for saving electricity!

How does LED lighting work?

LEDs work by creating a junction between two slightly different versions of the same kind of semiconductor. Each type contains a low concentration of different elements which either add extra electrons to the material, making it n-type (n for negative) or remove electrons (p-type). When the two types are joined together and a voltage is applied in the right direction, the extra electrons move from the n-type material to the p-type material, filling in the missing electron 'holes' and releasing light.

The wavelength of the light produced depends on the kind of semiconductor used. To create light of different colours, we need different materials: red LEDs are based on GaAs and blue LEDs are based on GaN. To make white light, we can either combine red, green and blue LEDs, or we can take a blue LED and coat it with a phosphor which converts some of the blue light into yellow light. However, we don't yet have materials which can emit green light efficiently enough, so at the moment, white LEDs are made by the second method.

You can already find these LEDs for sale in torches and bike lights. If the phosphor isn't coated evenly, then you can see the individual blue and yellow components when you shine the light onto a piece of white paper (go on, try it!).

Blue-green LEDs made at Cambridge

Ga = gallium

As = arsenic

N = nitrogen

So GaAs is gallium arsenide and GaN is gallium nitride.

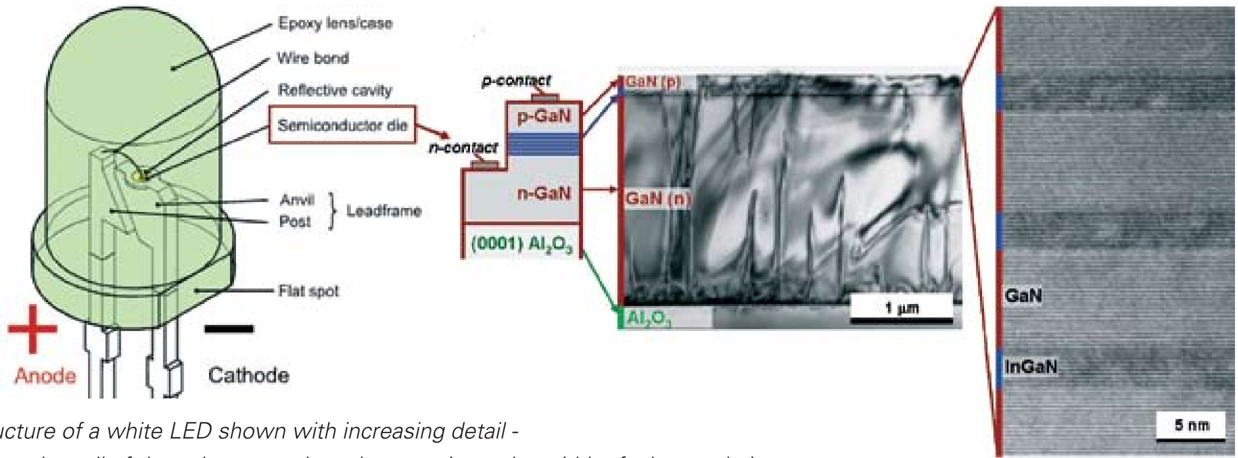
Box 2

How are white LEDs made?

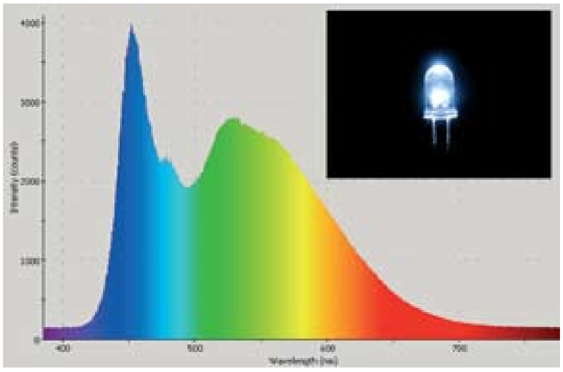
We start with a cheap, thin crystalline wafer of silicon or aluminium oxide. Very thin layers of GaN are deposited on the wafer using gaseous chemicals, which react on the surface of the wafer when it is heated to around 1000 °C.

$$Ga(CH_3)_3 + NH_3 \rightarrow GaN + 3\ CH_4$$

Firstly, we make an n-type GaN layer by adding very small amounts of SiH_4 to the reactor, which allows silicon (an electron donor) to be incorporated into the GaN. Then we deposit a very thin film of InGaN, just a few atomic layers thick. The composition of this film determines the exact colour of the light produced. Then we add a top layer of GaN, which contains very small amounts of magnesium (an electro acceptor) to make the GaN p-type. Then we cut up the wafer into individual pieces and coat them with yellow phosphor. Finally, each piece is packaged up into a finished LED.



The structure of a white LED shown with increasing detail -
Taken together, all of those layers are less than ten times the width of a human hair, but it takes a machine the size of a classroom to make them!



The spectrum of light emitted by a white LED

Equipment used to make LEDs. It is so big, we had to knock down the wall of the laboratory to bring it indoors!

Why aren't we using LED lighting in our homes?

It takes a lot more energy to light a whole room than it does to light up a small area. Unfortunately, when we try to get more light out of each LED by passing a lot of current through it, the efficiency drops and a lot of heat is generated. This means we have to use more LEDs in each lighting unit, making them too expensive for many people to buy. To encourage people to use LED lights, we have to make them cheaper by making each LED extremely efficient, even under high power operation. At Cambridge, our research concentrates on reducing the density of crystal defects in the light-emitting region of the LEDs, because these are the main cause of low efficiencies.

Box 2 above describes how we go about making high-efficiency white LEDs.

So what does the future hold?

As efficiencies rise and LED costs go down, we can expect to see LEDs appearing in our homes and offices. This is good news for everyone, because LED lighting has been shown to cure the 'winter blues' and can help to prevent depression, eating disorders and immune system problems. This is because the light that LEDs produce is much closer to daylight than that from other light sources. Indeed, this combination of health benefits and energy efficiency points to a brighter future for us all!

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