Beyond the Fire

Dr Stephanie Liggins, Principal Scientist at Element Six, explains how this part of De Beers Group is leading innovation in synthetic diamond applications for industry.

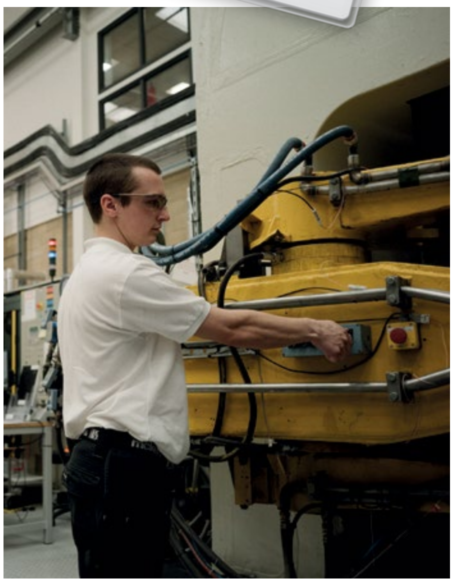
Diamond's properties stretch far beyond its aesthetic appeal as a gemstone for jewellery. Its extreme and diverse characteristics make it the material of choice in a range of industrial applications including the machining of the latest smartphones, high power lasers, high-end audio systems and in quantum enabled sensing devices.

From as early as the 16th century, small grains of diamond have been used to cut and polish other diamonds; something so hard needs something equally hard to polish it. Today, diamond's many extreme properties make it a valuable commodity for many industrial applications, but the variability and scarcity of natural diamonds makes many of these technological advances unsustainable.

SYNTHESISING NATURE

Element Six employs two methods to synthesise diamond material on a timescale of days. The first of these is high pressure, high temperature (HPHT) synthesis, which mimics the conditions under which diamond naturally forms. HPHT production is ideal to meet the demand for a wide range of abrasive applications, where materials can be adapted to suit challenges in areas including manufacturing in the automotive and consumer electronics industries, cutting and drilling in the oil and gas industries and in components for mining, road and wear applications.

The second is chemical vapour deposition (CVD), a low-pressure technique using a plasma chamber. CVD technology has been developed to enable diamond's broad engineering potential, making available a material that has not only consistent characteristics but one that can be tailored and specific to an end application.



An employee operating one of Element Six's HPHT presses.

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The diamond tweeter dome, designed and manufactured by Element Six in collaboration with Bowers & Wilkins. The third component from the left is the synthetic diamond tweeter dome (above).

Element Six Diamox™ cell with boron doped diamond wafer for wastewater treatment (left and below).
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CVD grown material uses gas chemistry with a small fraction of carbon in a surplus of hydrogen, heated to temperatures in excess of 2,000°C. This forms the fundamental building blocks of our diamond and, through the addition of gas dopants such as boron or nitrogen and the careful control of temperature and pressure, we can manipulate our processes to deliver polycrystalline or single crystal diamond, that may be electrically insulating or conductive, optically opaque or transparent, or even a range of different colours.

REVOLUTIONISING WASTEWATER

At a time where water supply is a global concern, driven by population growth and global industrialisation, the demand for clean water is growing at an extreme rate. Industries in developed nations consume more than half of the available water, and the wastewater produced is often low in biodegradability and has a high chemical oxygen demand. This means it consumes high levels of oxygen during the decomposition of the organic matter and the oxidation of inorganic compounds, which can starve aquatic life.

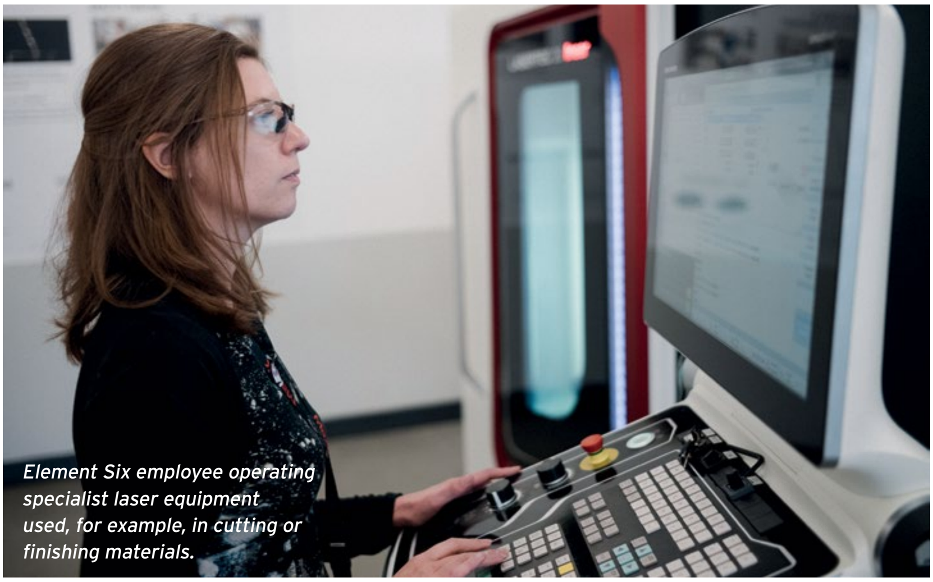
Using boron doped conducting CVD diamond grown in our labs, Element Six helped to pioneer electrochemical oxidation for treating otherwise hard to treat water waste. Electrically conductive diamond retains all its physical properties including chemical inertness, perfect for the manufacture of free-standing electrodes for harsh environments. These electrodes can operate at higher current densities than conventional electro-chemical components and the diamond electrode has a much lower catalytic effect on water.

Rather than electrolysing the water to generate O_2, a weaker oxidant, it instead oxidises the hydroxyl ions naturally occurring in water to form the critical radicals. These short-lived species have little effect on the electrode itself but have the oxidation potential to fully oxidise or mineralise the undesirable species (organic pollutants) in the waste. This inertness to the process and extreme effluent environment allows the electrode to have a lifetime measurable in years compared to market alternatives able to survive just hours.

CLARITY IN SOUND

Whilst industrial applications are Element Six's primary focus, our research also looks at consumer applications. Utilising diamond's stiffness and low mass resulting from its unique crystal structure, polycrystalline CVD diamond is an ideal material for the manufacture of tweeter domes for use in speaker systems. The tweeter dome is designed to replicate high audio frequencies, typically from 2 kHz upwards without distortion.

The figure of merit used to describe the quality of a tweeter is the break-up frequency, the driving frequency at which the dome no longer acts as a perfect rigid piston and instead begins to vibrate in sections. Tonal abnormalities result, where the generated waves from these different sections start to interfere with each other, giving the sound a different texture to that desired. For tweeters, focused at generating the high frequency sounds, this break-up frequency needs to be as high as is possible.



Element Six employee operating specialist laser equipment used, for example, in cutting or finishing materials.

The break-up mode is a function of geometry and material and therefore the material speed of sound. This formed the challenge for our scientists, how to design the perfect geometry, radius of curvature, thickness and diameter that would give the perfect performance and push unwanted resonances beyond the listener's audible range. In 2004, the diamond tweeter dome was launched in collaboration with Bowers and Wilkins and can now be found in studios including Abbey Road in London.

SOLUTIONS TO SHAPE THE FUTURE

At Element Six we are continuously looking to develop synthetic diamond solutions that will enable next generation technologies, such as quantum magnetic field sensors that have the potential to be used, for example, in medical diagnostics.

With the field of synthetic diamond science moving so incredibly quickly and the technical challenge of developing material for new applications, we are continuously developing our CVD techniques to produce incredibly pure synthetic single crystal diamond with nano-engineered precision and control.

In 2015, engineered diamonds were part of a landmark experiment testing quantum mechanics, reported in *Nature*. Such ground-breaking research is extraordinary and promises to revolutionise information technologies.

In 2018, our synthetic gemstones were launched under the Lightbox brand, focusing on white, pink and blue stones for use in jewellery.

Today, our research continues, not only to exploit the natural beauty of diamond, but to maximise the advantages it has in industry, beyond its fire and sparkle. ■

All images courtesy of Element Six.

PHYSICS

ABOUT THE PHYSICIST

Dr Stephanie Liggins
Principal Scientist, Element Six

Education: PhD in Physics, University of Warwick (2010)

Career Highlights: Stephanie joined Element Six – a global leader in the design, development and production of synthetic diamond and tungsten carbide super-materials – as a research scientist and has been the technical lead on projects including the development of the diamond tweeter dome. She now leads the Lightbox research and development programme. Stephanie enjoys the collaborative customer focus in her projects, identifying customers' key technical challenges, developing novel solution concepts and seeing them through to commercialisation at one of Element Six's production facilities.