////**Title: Exploring Diamond's Potential in High-Power, High-Temperature Electronics**

////**Stand-first**:

While many people perceive diamond as a material used to make jewellery or other decorative objects, this mesmerising stone has numerous other valuable applications. In fact, its physical properties make diamond ideal for uses in various technological applications, including high-performance electronics. Dr Debarati Mukherjee (deb-ar-AH-tee muck-er-JEE), Dr Luis Nero Alves (loo-iss ne-row al-vays) and Dr Joana Catarina Mendes at the University of Aveiro in Portugal have recently outlined some exciting potential uses of diamond in technology and engineering, while also describing what makes this material so unique and valuable.

////**Body text:**

Diamond, the renowned crystalline stone made of pure of carbon, is a naturally occurring material found in over 30 countries worldwide. Diamond crystals form under the Earth's surface, at depths of approximately 150 kilometres, where temperatures and pressures are remarkably high. They are then forced to the Earth's surface by natural phenomena, such as volcano eruptions or earthquakes.

For centuries, humans have been using diamond to create objects of adornment, due to its unique way of reflecting and refracting light. In addition to its captivating appearance, however, this material has a number of advantageous physical properties, including its remarkably high thermal conductivity and resistance to environmental damage.

In a paper published in [trade magazine Power Electronics Europe], Dr Mukherjee, Dr Alves and Dr Mendes at the Institute of Telecommunications / University of Aveiro reviewed the history of diamond in engineering, and outline the key qualities that make this material a promising candidate for high-performance electronic technologies.

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In their paper, the researchers outline the differences between diamond that forms naturally and that synthesised in the lab. They explain how General Electric was one of the first companies to report the successful synthesis of diamond in the lab, back in 1955. This was achieved by replicating the extreme conditions that enable the material's natural formation, using a machine called a high-pressure high-temperature reactor.

This process involves bathing a tiny fragment of natural diamond in molten graphite, which is a material comprising molecular sheets of pure carbon. By combining it with a catalyst and then placing it inside the reactor at extreme temperature and pressure, the carbon gradually precipitates onto the real diamond, increasing its volume.

Diamond produced inside high-pressure high-temperature reactors compares very favourably with naturally occurring diamond. Interestingly, it can even have fewer defects that natural diamond, while sometimes exhibiting even better thermal conductivity and hardness.

Unfortunately, this technique only enables the creation of diamonds that are a few cubic millimetres in size, which limits their potential for large-scale electronics applications. Despite this disadvantage, this method is now used to create synthetic diamond for a number of commercial and industrial applications.

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Another technique used to synthesise diamond, known as chemical vapor deposition, involves growing a diamond layer on a wafer, using highly-energised carbon-rich gases as the source of carbon atoms. This strategy, which initially appeared to be impossible to realise, became a viable option in the 1980s, after a team of scientists in Japan successfully implemented it. Their proposed method was later refined and optimised, ultimately enabling the production of diamond on wafers with large areas, overcoming the key limitation of diamonds synthesised in high-pressure high-temperature reactors.

While this method is cheaper and more effective for producing large quantities of diamond, it often involves the use of non-diamond wafers. As the researchers describe in their paper, this can compromise some of the resulting material's beneficial properties.

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The researchers also outline the physical properties of diamond that are most valuable for engineering applications. Firstly, due to its hardness, diamond is often used by mechanical engineers to drill, cut, grind and polish other materials. In fact, diamond is the hardest known naturally occurring material.

In electrical and electronics engineering, diamond has also proved useful for a variety of applications. For instance, due to its extremely high thermal conductivity, diamond can be used to create high-temperature and high-power devices. Because pure diamond is a good electrical insulator, while diamond doped with other atoms can act as a semiconductor, it is an ideal material for fabricating transistors and integrated circuits.

A transistor is a semiconductor-based device that regulates the flow of electrical current, acting as a switch for electronic signals. Integrated circuits, which contain a network of interconnected transistors on a chip, can perform a variety of functions, such as acting as computer memories, amplifiers, or microprocessors. These chips are fundamental components of all electronic devices, ranging from laptops to smartphones, and from fitness trackers to supercomputers.

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Over the years, researchers have developed increasingly smaller transistors, towards the creation of devices that are faster and more powerful. As transistors become smaller, however, some problems start to emerge, particularly in terms of the dissipation of the electric power which leads to increasing operating temperatures.

A technology commonly used to lower the power consumption – and thus the operating temperature - of modern electronic devices is complimentary MOS (moss), or CMOS (see-moss). CMOS technology involves a complimentary arrangement of transistors that can reduce power consumption in a wide range of battery-powered devices.

In recent years, however, researchers realised that existing CMOS technologies might be far from ideal, as they sometimes reduce the overall performance of devices and lead to undesirable interference. Building CMOS devices using different semiconducting materials could help to overcome these challenges, allowing devices to maintain a high performance with a lower power consumption.

In their paper, the researchers describe how diamond could be the ideal candidate for fabricating CMOS devices, particularly a type of diamond known as hydrogen-terminated diamond. In recent studies, transistors made from hydrogen-terminated diamond have demonstrated remarkable performance. As this type of diamond conducts heat well, it could be integrated within CMOS technologies, greatly enhancing performance.

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As transistors continue to shrink in size, researchers predict that quantum effects will play an increasingly key role in their functioning, leading to the development of new types of logic or memory devices.

In addition to being used for the development of conventional transistors and electronic chips, diamond could play a role in the creation of these new kinds of devices. However, before diamond can be used to create electronics on a large-scale, several challenges will need to be overcome.

As highlighted by the researchers, the most crucial challenge preventing the widespread use of diamond in technology development is the lack of available diamond wafers that are affordable, have large surface areas, and retain the material's most desirable properties.

Research groups worldwide are thus currently investigating the potential of new strategies to produce diamond in the lab, particularly two techniques known as epitaxial lateral overgrowth and mosaic wafer fabrication. In the future, if scientists can optimise these methods to enable the large-scale and affordable production of diamond wafers with greater surface areas, this could lead to the creation of electronic components with truly exceptional qualities.

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This SciPod is a summary of the article 'Diamond for Future (Power) Electronics', from trade magazine Power Electronics Europe.

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