SOUTH WEST NUCLEAR HUB

University of BRISTOL
Cabot Institute

Diamond Battery FAQs

What voltage does the diamond produce?

The Ni63 version has produced close to 1.9V.
The C14 version would be expected to achieve at least 2V.

What is the capability of the Diamond Battery versus a normal battery?

Standard alkaline AA batteries are designed for short timeframe discharge: one battery weighing about 20g has an energy storage rating of 700J/g. If operated continuously, this would run out in 24 hours.
In comparison, a diamond beta-battery would be designed to last longer. The actual amount of C14 in each battery has yet to be decided but as a rough guide, one battery, containing 1g of C14 will deliver 15J per day (based on calculations extrapolated from Ni63 prototype). On the face of it, this is less than an AA battery. However, it will continue to produce this level of output for 5,730 years, so its total energy storage rating is very high (2.7TeraJ aka million million Joules).

What is the approximate volume of the battery?

The approximate volume of the prototype diamond devices we are working on are 10 mm x 10mm with a thickness up to 0.5 mm. This is the 'active' device and does not include the metallic contacts and wiring to complete the circuit.

What is the current rating over temperature?

We expect the current rating to be near continuous with temperature. We already know that as a detector material the diamond doesn't require heating to work and we also know that it has good stability up to many hundreds of degrees. We have heat cycled the diamond structures to 750C to evaluate the material stability but have not yet tested their power output under elevated temperature ambients.

Is the battery technology scalable?

In short – yes! Much like a normal battery consists of multiple cells we could also sum currents from multiple cells to up the power output.

How far away from potential practical application is this process?

We are still at TRL 2 at the moment and currently seeking funding to take the concept forwards through a series of more complex and efficient prototypes. One route is to grow the isotopically layered C-14/C-12 diamonds in the lab from high purity gases. For this we require substantially larger quantities of C-14 methane than we currently have available. Another possible route is to grow Nitrogen-doped diamond in the lab and then irradiate it in a reactor to grow-in the C-14 and subsequently deposit 'clean' diamond on the outside. This would achieve the same effect but without full isotopic purity. We are about to do this in the research reactor at KURRI in Japan.

Are these synthetic diamonds similar in appearance to those used in conventional jewellery?

No the diamond is in the form of a sandwich composed of thin layers each made up of large polycrystalline grains rather than the single crystal diamond found in jewellery.

What happens to the C-14 when it undergoes radioactive decay?

Carbon 14- decays to nitrogen-14 by beta emission. The beta particle is essentially a high energy (Average decay energy 50keV) electron and in our device this initiates a cascade of low-energy electrons which are collected by the outer electrode. Over time this leads to a build-up of nitrogen but doesn't destroy the diamond structure because nitrogen is surprisingly soluble. Diamond has a solubility limit for substitutional nitrogen close to $2 \cdot 10^{18}$ cm^{-3} in CVD-formed diamond. It would take hundreds of years for this transformation to become noticeable on the performance of the device mainly because the majority of the current is generated in the bounding (and isotopically pure) 'clean' diamond layers.

How is current generated and how does it flow?

As explained above the beta particle released by each C-14 decay moves into the surrounding diamond structure creating successive electron hole pairs due to inelastic impacts with other carbon atoms and generates a cascade of lower energy electrons that are collected at the metal contact to the diamond. In conduction terms, diamond is a semiconductor (like silicon) and like the operation of a silicon solar panel cell, electric current flows when valence electrons are given enough energy to be promoted into the conduction band.

What sort of costs are involved in processing the nuclear waste into diamond battery form?

The exact costs for waste processing are not known. However, cost estimates for disposing of the graphite waste are £46k/m^3 for ILW and £3k/m^3 for LLW. Therefore, if the waste processing to remove the C14 reclassifies the waste as LLW, then any cost under £43k/m^3 will represent a saving to the UK taxpayer.

What type of scale will be required for commercial viability?

We are still at TRL 2 at the moment and currently seeking funding to take the concept forwards through a series of more complex and efficient prototypes. Commercial viability is an aspect that will be investigated through the project, in partnership with the Research and Development (RED) team at the University of Bristol.

Is there an optimum quantity of carbon-14 that provides the best power to weight ratio?

In short, yes there probably is as the cost of C14 is the largest part, and so increasing the C14 for little gain in power will not be economically viable. However, the exact quantity is still to be determined and will be investigated through the ongoing work.

How is power transferred from the diamond to the device it powers?

It is unlikely that the diamond battery will provide direct power to the attached device. More likely is that it will be associated with a capacitor that will be 'trickle charged' by the battery and then discharge at set intervals, to power devices at set intervals or to continually power law draw devices.

What are the next steps in the research?

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What are some of the best suggestions you've had from the public via the #diamondbattery hashtag?

We have collected some of the best suggestions in a blog post.

So that is great in terms of lifetime, but it seems like it has limits to the amount of power it can generate on a short time scale and therefore what it can actually be used for?

This technology is not a replacement for AA batteries! The applications for this technology are focussed around long lifetime, low power devices such as small electronics associated with space exploration, medical devices, seabed communications etc. In essence, the technology is designed for applications where low power is required to keep devices on/retain memory etc and where changing a battery is not possible/inherently expensive.

Could you 'string' these together/ link them up/ add them together to create a greater source of energy?

In short – yes! Much like a normal battery consists of multiple cells we could also sum currents from multiple cells to up the power output.

How big could the diamonds be? I.e. if you can have 1g = 15J per day, what if you had 20g?

One limitation is the amount of C14 diamond that can be manufactured. The maximum size of synthetic diamond manufactured using chemical vapor deposition is limited.

Could they be small enough to power nanobots?

This would be dependent on the energy requirements for the nanobots, as the size of the device is proportional to the energy output required.

How energy intensive is the process of creating the diamond? Thus, what is the return on energy investment?

The exact costs for waste processing to retrieve C14 are not known but are likely to dominate the cost of the device. The actual cost of manufacture of the devices once a suitable feedstock gas is available is relatively small and so should be economically viable.

What about U-238, U-234, Np-237 etc?

Other radioisotopes could be used, however the benefit of C14 is that it emits only beta radiation. This means that it can be made passively safe by surrounding the radioactive element of the device with non-radioactive diamond. Other radioisotopes may emit gamma radiation which will not be shielded by the surrounding diamond, and so are less likely to have public assurance that they are safe and will require additional shielding to make them safe. Such shielding will make the devices larger, heavier and more expensive and so would limit their use.

Are there any published papers available?

As we are still at TRL 2 at the moment and in the early stages there are no published papers on this exact project. The research team are working towards publicising the prototype results after patents have been completed and filed.

What is the cost?

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Press release: http://www.bristol.ac.uk/cabot/research/casestudies/2016/diamond-battery.html

Video: https://www.youtube.com/watch?v=b6ME88nMnYE