



## PATENTS ACT 1977

APPLICANT                    Element Six Technologies US Corporation

ISSUE                         The Patents Act 1977: whether patent application  
GB1415353.0 complies with Section 14(5) of the Act

HEARING OFFICER                    Dr L Cullen

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### DECISION

#### Introduction

- 1 This decision concerns patent application GB1415353.0, entitled “*Semiconductor device structures comprising polycrystalline CVD diamond with improved near-substrate thermal conductivity*”, which was filed in the name of “Element Six Technologies US Corporation” (hereafter the applicant) on 29 August 2014 claiming an earliest priority date of 02 September 2013. The application was published in the UK on 01 April 2015 as GB2518752A.
- 2 Despite a number of rounds of correspondence with the applicant which included amendments to the claims, the examiner maintained that independent claim 1 lacks clarity under section 14(5) of the Patents Act 1977 (hereafter the Act) because it defines the invention by means of a result to be achieved. The examiner also considered that claim 1 is not supported across its entire scope. These issues came before me at an oral hearing at the IPO in Newport on 23 August 2016.
- 3 At the hearing the applicant was represented by Dr Ian Atkinson of Element Six Limited Group Intellectual Property. Also present at the hearing was the Examiner, Mr Thomas Britland. Dr Bill Thomson acted as hearing assistant.
- 4 Following the hearing, the applicant was asked, in the official letter dated 25 August 2016, to provide details in support of their argument at the hearing that the use of Raman spectroscopy to characterise the structure of diamond layers in semiconductor devices was well known. Written submissions were received in response on 7 September 2016 in the form of a witness statement from Mr Joseph Michael Dodson, an employee of the applicant with experience in the field of polycrystalline CVD diamond synthesis.
- 5 In reaching my decision below, I have taken account of the correspondence between the applicant and examiner, the oral hearing and the written submissions.

## The Invention

- 6 As the background to the invention points out, management of the heat generated by all electronic and optoelectronic devices in operation is a critical design feature. The goal of efficient heat or thermal management is to lower the operating temperature of such electronic or optoelectronic devices while maximizing performance (power and speed) and reliability. Electronic and optoelectronic devices made on a III-V semiconductor substrate such as Gallium Nitride (GaN) are limited in performance due to the relatively low thermal resistance of the substrates commonly used to grow this substrate. This limitation is most pronounced in GaN based devices where reduced cooling requirements and longer device life are required, such as high-power microwave and millimetre-wave transistors and amplifiers. Diamond is the most thermally conductive substance known to man and for this reason, the semiconductor industry has used diamond heat-sinks and diamond heat spreaders for improved thermal management since it has been possible to obtain synthetic diamond by chemical-vapour deposition (CVD). For optimal heat management, the diamond heat-spreader or layers of diamond must be brought into close proximity to the heat source in the electronic or optoelectronic device, for example, by building the device on thin chips, mounting the device on a diamond heat-spreader, coating the device with diamond layers, or transferring device epilayers onto diamond.
- 7 The invention in this case relates to a method for depositing polycrystalline diamond on non-diamond substrates, such as GaN, using CVD and to semiconductor device structures prepared using this method. The aim is to achieve low thermal resistance at the boundary between the substrate and the diamond layer such that thermal management issues are minimised. The applicant has developed a fabrication process where at early stage nucleation, i.e., the stage where the diamond carbon is first deposited onto the surface of the substrate, such as GaN, the quality and thickness of the diamond layer can be optimized such that it is more crystalline in nature and therefore of a higher thermal conductivity.
- 8 I shall refer to the layer of diamond formed on the GaN substrate surface as the substrate-diamond interface layer.

## The Claims

- 9 The most recent set of claims, filed on 13 January 2016, includes 26 claims, of which claim 1 and claim 18 are independent: claim 1 concerning a semiconductor device and claim 18 concerning a method of fabricating the device of claim 1. The two independent claims read as follows;

### **Claim 1:**

*“A semiconductor device structure comprising: a layer of III-V compound semiconductor material; a layer of polycrystalline CVD diamond material; and an interface region between the layer of III-V compound semiconductor material and the layer of polycrystalline diamond material, the interface region including a diamond nucleation layer of polycrystalline CVD diamond which is formed during an initial nucleation phase of polycrystalline CVD diamond growth over a*

substrate comprising the layer of III-V compound semiconductor material, wherein the diamond nucleation layer is such that a Raman signal generated by a laser focused on a region comprising the diamond nucleation layer exhibits an sp<sup>3</sup> carbon peak at 1332 cm<sup>-1</sup> having a full width half-maximum of no more than 5.0 cm<sup>-1</sup>, wherein the diamond nucleation layer is such that said Raman signal further exhibits one or both of the following characteristics:

- (i) an sp<sup>2</sup> carbon peak at 1550 cm<sup>-1</sup> having a height which is no more than 20% of a height of the sp<sup>3</sup> carbon peak at 1332 cm<sup>-1</sup> after background subtraction when using a Raman excitation source at 633 nm; and
- (ii) the sp<sup>3</sup> carbon peak at 1332 cm<sup>-1</sup> is no less than 10% of local background intensity in a Raman spectrum using a Raman excitation source at 785 nm, and

wherein an average nucleation density at a nucleation surface of the diamond nucleation layer is no less than  $1 \times 10^8$  cm<sup>-2</sup> and no more than  $1 \times 10^{12}$  cm<sup>-2</sup>,

wherein the diamond nucleation layer has a thermal boundary resistance of no more than 50 m<sup>2</sup>K/GW.

and

**Claim 18:**

“A method of fabricating a semiconductor device according to any preceding claim, the method comprising:

- providing a substrate comprising a layer of III-V compound semiconductor material;
- seeding a surface of said substrate;
- growing a diamond nucleation layer on said surface using a chemical vapour deposition (CVD) technique; and
- growing a thicker layer of polycrystalline CVD diamond material over the diamond nucleation layer,
- wherein the method further comprises applying the following techniques:

(i) using a nanocrystalline diamond powder for the seeding step, the nanocrystalline diamond powder having an average particle size of no more than 200 nm and a D90 particle size of no more than 500 nm thereby reducing the size in the grooves formed in the substrate surface and consequently reducing void formation during diamond growth thereon when compared with a seeding process which utilizes larger seed particles;

(ii) using alternating CVD diamond growth and non-diamond carbon etch steps to fabricate the diamond nucleation layer, the technique comprising growing a diamond layer of a first thickness by chemical vapour deposition, etching at least part of said diamond layer, repeating said steps of growing and etching at least a part of said diamond layer until an overall thickness of said diamond layer reaches a second thickness, wherein said step of etching at least part of said

*diamond layer etches non-diamond phases preferentially over diamond phases thereby increasing the proportion of diamond phase in the diamond nucleation layer relative to non-diamond phases; and*

*(f) using a pre-growth etching step applied to the substrate surface after seeding and prior to growth of the diamond nucleation layer thereon, wherein crystalline seeds are deposited on the substrate surface during seeding and the pre-growth etching step comprises etching using a chemistry which is selected to etch the substrate surface preferentially over crystalline seeds on the substrate surface and to smooth the substrate surface thereby reducing nucleation sites formed by sharp groove edges on the substrate surface relative to nucleation sites provided by the crystalline seeds.*

- 10 I note that the outstanding objections raised by the examiner which are the subject of the present decision all relate to claim 1 and its dependent claims.
- 11 Also for convenience I will continue to use the term 'sp<sup>2</sup>' and 'sp<sup>3</sup>' as used by the applicant in the claims to refer to the different types of hybridised carbon atom in graphite (non-diamond carbon), i.e. sp<sup>2</sup> hybridisation, and diamond, i.e. sp<sup>3</sup> hybridisation.

### **The Issues to be decided**

- 12 Firstly, I will consider if claim 1 to the "semiconductor device structure" lacks clarity because it defines the device structure in terms of the result to be achieved, i.e., the device structure has a diamond nucleation layer with certain specific Raman characteristics.
- 13 Secondly, I will consider if claim 1 is supported across its full breath, given that only one embodiment of the invention is disclosed in the application as filed.
- 14 If I decide that claim 1 does not lack clarity and that it is supported across its full breath, I will remit the application back to the Examiner to complete his consideration of the application under Section 18 of the Act.

### **The Law**

- 15 Section 14(5) of the Act sets out a number of requirements that the claims must meet for a patent to be granted. The provisions in this section that are relevant to the current case are:

*The claim or claims shall –*

- a. ....
- b. ....
- c. **be clear and concise;**

**d. be supported by the description**

- 16 With regard to section 14(5)(c) and the clarity of the claims at issue, it is a well-established principle that the area defined by the claims must be as precise as the invention allows. As a general rule, claims which attempt to define the invention, or a feature thereof, by a result to be achieved are not allowed<sup>1</sup>.
- 17 Such claims may be allowed, however, if the invention can only be defined using such an approach and if the result is one that can be verified, directly and positively, by tests or procedures which are described in sufficient detail in the application, involve nothing more than trial and error and do not require inventive ingenuity. This situation arose in *No-Fume Ltd v Frank Pitchford Co Ltd*, (1935) 52 RPC 231. This was a Court of Appeal decision. In this case, a claim to an ash receptacle for smokers, in which the dimensions of certain parts were expressed in terms such that smoke from objects thrown into the receptacle did not emanate from the receptacle as distinct from dimensions, for example, related to distance or shape or curve etc., was found to be sufficient and unambiguous. Although the dimensions were not specified and were, according to the description “*so chosen that the cooling or condensation of the collected smoke is assured*”, the court found that “*there is a sufficient explanation of what the dimensions are to be*” when “*one bears in mind throughout that you are constructing an ash receptacle for smokers' use*”. The invention covered by the claim was allowed on the grounds that the invention could be realised by dimensions other than those disclosed which could be determined using experiments that did not involve inventive ingenuity.
- 18 Thus, I consider that an invention may be defined by a result to be achieved in the situation where it can only be defined in that way. The invention may not be defined by a desired result when there is another way to define the invention.
- 19 With regard to section 14(5)(d) when considering whether or not the claims are supported by the description, I will follow the approach outlined by Aldous J in *Schering Biotech Corp's Application* [1993] RPC 249 (see page 252, line 49 to page 253, line 4) where he indicated that

*“to decide whether the claims are supported by the description, it is necessary to ascertain what is the invention which is specified in the claims and then compare that with the invention which has been described in the specification. Thereafter the court's task is to decide whether the invention in the claims is supported by the description. I do not believe mere mention in the specification of features appearing in the claim is not necessarily sufficient support. The word 'support' means more than that and requires the description to be the base which can fairly entitle the patentee to a monopoly of the width claimed.”*

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<sup>1</sup> See Chapter 14 of IPO Manual of Patent Practice [here](#), in particular, paragraphs 14.118 – 14.120 and 14.142-14.156

## Argument and analysis

- 20 The examiner argued, as set out in his examination reports of 23 January 2015 and 20 November 2015, that claim 1, in referring to the diamond nucleation layer in terms of a Raman spectrum, is defining the semiconductor device structure by a result to be achieved and not by an essential technical feature, i.e., the device is not wholly defined by the actual physical properties of the device. The examiner was thus of the view that the invention resided in the method of manufacture of the device and that, in light of the judgement in *Kirin-Amgen Inc v Hoechst Marion Roussel Ltd* [2005] RPC 9, the protection conferred to any method claim also applies to the products directly obtained from that method.
- 21 The agent, in their response on behalf of the applicant dated 13 January 2016, stated that one cannot readily determine if someone is infringing a manufacturing process, hence they sought the product claim as well as the method claim. The agent questioned how would one know if a product had been manufactured using the method defined in the current application or not, unless one was present to see it being so. In their view, proving that a third party product was made by the same method as that in the claims could be very difficult legally and expensive financially to resolve. He argued that the method claim, whilst admittedly protecting products made using the claimed method, should not preclude the applicant from also claiming the new and inventive product.
- 22 At the hearing, Dr Atkinson spent a significant amount of time explaining what was the background and context of the invention, i.e. what was the state of the art. He first began by summarising how semi-conductor devices involving gallium nitride (GaN) are made. The GaN layer of a few nanometres is grown on top of a substrate layer of a few hundred nanometres, usually Silicon or Silicon Carbide, and the electrodes for the device are in turn laid down on top of the GaN layer. In operation, heat is generated by flow of electrons in the top GaN layer and the issue is how best to dissipate this heat so that it does not cause problems. Substrates such as Silicon or Silicon Carbide are poor heat conductors, whereas using diamond as a substrate to grow the GaN provides a material which can be used to prepare semi-conductor devices which will have a much more effective means to dissipate the heat.
- 23 Dr Atkinson briefly outlined the different approaches that have been taken to produce semiconductor devices which integrate gallium nitride (GaN) and diamond. The applicant's approach is to grow the diamond directly on the surface of the GaN layer. As the application points out (see paragraph bridging pages 3 and 4) the surface of the non-diamond material has to undergo a surface preparation and nucleation phase in order to encourage the formation of a crystalline diamond layer which will have the desired thermal conductivity properties. The size of the grains that make up the initial crystals of diamond that form on the non-diamond substrate is critical – if the grains that grow are too small there will be a lot of grain boundaries and this results in poor conductivity in the region referred to as the substrate-diamond interface region.
- 24 Using standard seeding and growth conditions, the applicant was not able to obtain devices with thermal and electronic properties predicted by modelling. The applicant looked at the GaN substrate layer to see if there had been damage caused by the growth of diamond onto the surface of the GaN. No damage was observed. The applicant then looked at the interface region between the diamond layer and the GaN

semiconductor layer, which as indicated above, I have referred to as the substrate-diamond interface region. This interface region includes the nucleation layer of polycrystalline chemical vapour deposition (CVD) diamond which is formed directly on the GaN substrate during the initial phase of CVD diamond growth. As this is the foundation on which the diamond layer is built, it is important that it possesses certain characteristics in order to deliver good thermal conductivity – it should have a high degree of crystalline diamond, it should not have a high proportion of voids, it should not have a high number of grain-to-grain boundaries or grain-to-void boundaries as these all increase thermal resistance. These factors are hardest to control in the interface region as the diamond is being grown on a non-diamond substrate

- 25 The applicant examined the thin layer of diamond in the interface region using the technique of Raman spectroscopy at a Raman excitation wavelength of 633 nm and found that it comprised a significant proportion of sp<sup>2</sup> carbon at 1550 cm<sup>-1</sup> and a relatively small sp<sup>3</sup> carbon peak at 1332 cm<sup>-1</sup>. What this indicated is that the diamond nucleation layer is of poor quality when compared to the bulk diamond in the device – i.e., most of the carbon in the diamond nucleation layer is not actually crystalline diamond (as indicated by the sp<sup>3</sup> peak) but amorphous or graphitic carbon (as indicated by the sp<sup>2</sup> peak). This would explain the poor thermal and electronic properties of the devices made using standard diamond growth techniques.
- 26 The applicant then experimented with modified seeding and etching steps using nanocrystalline diamond powder and this resulted in devices with much improved thermal and electronic properties. When analysed using the aforementioned Raman spectroscopy techniques, the amount of sp<sup>2</sup> carbon in the diamond nucleation layer was significantly reduced whilst the amount of sp<sup>3</sup> carbon was significantly increased. These modified seeding and etching steps are illustrated in Figures 3-5 and Figure 7 shows the impact of the various steps used in the process of Figure 5 to promote the formation of a suitable substrate diamond interface region.
- 27 Using the well-established techniques of Scanning Electron Microscopy (SEM) and Tunnelling Electron Microscopy (TEM) to study the substrate-diamond interface region, the applicant was able to determine the range of grain sizes that would provide the appropriate thermal properties and this has been expressed as the density of such crystals formed in the substrate-diamond interface region i.e. the average nucleation density at a nucleation surface of the diamond nucleation layer is no less than 1 x 10<sup>8</sup> cm<sup>-2</sup> and no more than 1 x 10<sup>12</sup> cm<sup>-2</sup> (see second paragraph on page 12 of specification as filed). The applicant has also determined that the diamond nucleation layer with suitable properties will have a thermal boundary resistance of no more than 50 m<sup>2</sup>K/GW.
- 28 However, when one examines the specification as filed in its entirety and takes note, in particular, of the description of the semiconductor device of claim 1, one is struck by the fact that there is no worked example of the invention showing a Raman spectrum that corresponds to it, or that discloses the corresponding nucleation density, nor indeed shows how the thermal boundary resistance associated with an exemplified product is arrived at. I have considered very carefully what is provided in the specification as filed to show how the product of claim 1 is obtained and identified. Figure 1 shows how heat flow dissipates in a high-electron density transistor epilayer structure and so illustrates the problem that the invention is trying to address. Figure 2 illustrates the thermal boundary resistance in such a device. As noted above,

Figures 3-5 show the different steps in the method for making the product of claim 1 using the method of claim 18. Figure 7 illustrates the different types of structure that occur on the interface at each stage of the process described on Figure 5 which result in a diamond nucleation layer with suitable properties. In terms of information that explains how the device of claim 1 is made and characterised, Figures 6, 8 and 9 are considered to be the most relevant.

- 29 Figures 6A-6D show TEM images of the diamond nucleation layer in separate devices made by different processes. These show the thickness of the diamond nucleation layer and the thermal boundary resistance of these layers. Figure 9 shows a correlation graph indicating the relationship between thermal conductivity of a diamond nucleation layer and the full-width half maximum of the  $sp^3$  peak at  $1332\text{cm}^{-1}$  in the Raman spectrum. I have therefore to decide if the disclosure mentioned above in the context of the description forms a fair basis for the device being claimed. On the face of it, the Raman spectrum in Figure 8 and TEM images of Figure 6 are not linked – i.e., each is not associated with the same diamond nucleation layer in the same device. Further, each of the aforementioned do not have an appropriate nucleation density associated with the preparation of such a sample. However, what I believe the description is saying is that if you make a device using the techniques defined in claim 18 and control the nucleation density during diamond nucleation layer formation, this **should** result in a device with the appropriate Raman spectrum and the appropriate thermal boundary resistance (thermal conductivity).
- 30 I appreciate that the applicant has arrived at the optimum figure for the nucleation density range in their experiments, which feeds into the preparation method that results in the diamond nucleation layer being more “diamond-like” in the device. Looking at the disclosure in the description, I need to be sure that the skilled person upon reading it will arrive at a device that has the necessary thermal boundary/conductivity properties for the diamond nucleation layer. There is clear guidance in the description that the seeding step needs to be performed with nanocrystalline diamond powder ( $<200\text{nm}$ ) as this reduces the size of the grooves formed in the substrate during the seeding step which minimises void formation during the diamond growth step. A pre-growth etching step is then applied to the substrate surface to smooth any edges on the substrate surface so that when diamond growth occurs, it does so preferentially on the diamond rather than onto the substrate. Repeated etching and growth steps ensure that diamond growth dominates over non-diamond until a diamond nucleation layer of the required size is obtained. The description tells the skilled person that the nucleation density needs to be between  $1 \times 10^8$  and  $1 \times 10^{12} \text{cm}^{-2}$ , indeed the description on the last paragraph of page 24 does say that “*high nucleation densities above  $10^{10} \text{cm}^{-2}$  and as high as  $10^{11} \text{cm}^{-2}$  are reachable and may be required to achieve thermal boundary resistances below, for example,  $10 \text{m}^2\text{K/GW}$ .*”
- 31 As regards the quality of the diamond at the nucleation layer, the sample Raman spectrum in Figure 8 indicates to the skilled person where the peaks at  $1332\text{cm}^{-1}$  ( $sp^3$  carbon) and  $1550\text{cm}^{-1}$  ( $sp^2$  carbon) lie. Further, this particular spectrum is stated in the description on the last paragraph of page 31 to have a full width half-maximum (FWHM) for the aforementioned  $sp^3$  peak of  $2.9\text{cm}^{-1}$ . Considering this in combination with the correlation graph in Figure 9 tells the skilled person that in such a situation, the diamond nucleation layer in this particular sample will have a thermal conductivity

of 10 W/cm.K. This figure lies in the desirable higher range of thermal conductivities shown in this graph. Indeed, the correlation graph of Figure 9 tells us that thermal conductivity decreases with increasing FWHM values for the sp<sup>3</sup> carbon peak at 1332cm<sup>-1</sup>. One can clearly see that a figure of less than 5cm<sup>-1</sup> for the FWHM peak at 1332cm<sup>-1</sup> (as required by claim 1) correlates to higher thermal conductivity for the device. If this correlation for the FWHM of the sp<sup>3</sup> carbon peak at 1332cm<sup>-1</sup> for the Raman spectrum of the diamond nucleation layer not been present in the application as filed, I think that there would be a distinct lack of support in the description for the skilled person to arrive at a device of the invention. The correlation shows that the quality of the diamond at the nucleation layer is linked with the thermal conductivity of this important interfacial region in the device which is related to controlling the formation and size of diamond crystalline phase during nucleation.

- 32 Figure 8 shows a reference Raman spectrum of a CVD diamond nucleation layer to show where the peaks for sp<sup>3</sup> and sp<sup>2</sup> carbon typically occur. This is not a Raman spectrum from a CVD diamond nucleation layer prepared according to the method of claim 18 or from a product according to claim 1. This is clear from the description at page 30 (penultimate paragraph). Figure 9 then shows that there is a correlation between the thermal conductivity of a diamond film and the proportion of sp<sup>3</sup> carbon in this film as measured by the full-width-half-maximum of the sp<sup>3</sup> peak at 1332 cm<sup>-1</sup>
- 33 Dr Atkinson was asked to address three questions in the course of the hearing. Firstly, it was not immediately clear why there were two characteristics for the Raman spectroscopy performed on the device in claim 1 – i.e., spectra performed at 633 nm and at 785 nm. The former is more readily understandable than the latter as it gives a clearer indication of the amount of sp<sup>3</sup> carbon present in the diamond nucleation layer when compared to the amount of sp<sup>2</sup> carbon. Dr Atkinson stated that these were two well-known Raman excitation wavelengths characteristic of the presence of sp<sup>3</sup> carbon, which given known Raman sensitivities to sp<sup>2</sup> carbon at these wavelengths, could be used each on their own or both together depending on what type of laser light source(s) one had available for performing the Raman analysis..
- 34 Secondly, in contrast to the disclosure about the use of microscopy techniques (SEM/TEM) to study the surface of semiconductor materials, how well known in the art was the use of Raman spectroscopy as a technique to characterise solid state devices comprising diamond. It was not readily apparent from the description that this technique is widely used in this field. For example, while, it is referred to briefly in the paragraph bridging page 12 and 13 and the first full paragraph on page 13 of the description as filed, it was not referred to in the priority document. Dr Atkinson indicated that he would be able to provide additional material to support his assertion that the use of Raman spectroscopy as a technique to characterise solid state devices comprising diamond is well known.
- 35 The further submissions received from the applicant on 7 September 2016 address this point. In his witness statement, Joseph Michael Dodson, an employee of the applicant who has extensive experience in the field of polycrystalline CVD diamond synthesis, indicated that before the priority date of the current application, it was well known to measure the phase purity of polycrystalline CVD diamond using Raman spectroscopy, i.e. the amount of diamond to non-diamond carbon. Referring to the

paper from *Wagner et al. (1991)*<sup>2</sup> and the review form *Prawer & Nemanich (2004)*<sup>3</sup>, supplied with his statement, Mr Dodson explained that the peak at 1332 cm<sup>-1</sup> indicates the presence of sp<sup>3</sup> (diamond) carbon and that at 1550 cm<sup>-1</sup> indicates the presence of sp<sup>2</sup> (graphitic or non-diamond) carbon. The relative intensities of the sp<sup>3</sup> and sp<sup>2</sup> carbon peaks are dependent upon the Raman excitation wavelength used. If, for example, a red laser is used at 633 nm or an infrared laser at 785 nm, then a larger peak at 1550 cm<sup>-1</sup> (sp<sup>2</sup>) will be observed than would be the case if a green laser was used at 514 nm. Thus, for looking at the purity of a sample of diamond, use of a green laser is not sensitive enough to detect the presence of sp<sup>2</sup> carbon and the preferred Raman excitation wavelength is 633 nm or 785 nm, i.e., a red or infrared laser is preferable as that will best show if any sp<sup>2</sup> carbon is present. Indeed *Wagner et al.* shows that it was well known in the art to measure the phase purity of diamond using the ratio of the peak at 1332 cm<sup>-1</sup> to that at 1550 cm<sup>-1</sup> to discern the relative amounts of sp<sup>3</sup>/sp<sup>2</sup> carbon present. It was also established that the full width half maximum (FWHM) of the Raman line (i.e., peak at 1332 cm<sup>-1</sup>) is often taken as a measure of the 'perfection of the diamond crystallite', i.e. the quality of the diamond layer. Given the above and the statements from Dr Atkinson at the hearing, I am content that at the priority date, use of Raman spectroscopy was well known in the art as a technique with which to characterise the phase purity of polycrystalline diamond.

- 36 Thirdly, Dr Atkinson was asked how easy testing of the diamond nucleation layer would be on a device of the invention – i.e., would this be a routine process, devoid of any inventive input. Dr Atkinson stated that the GaN layer could be removed down to the nucleation layer by chemical (i.e., etching) or physical means (stripping). Such techniques are standard in the art. The exposed layer would then be subjected to Raman spectroscopy at an appropriate wavelength to determine sp<sup>3</sup>/sp<sup>2</sup> content and electron microscopy (SEM/TEM) would also be used to determine nucleation density and indeed to verify if there was a nucleation layer present at all. Dr Atkinson admitted that this testing would be destructive to the device, but it could be performed at a rate that ensures consistency in the batch of devices produced. This testing/sampling of the devices would be routine and easy to verify.
- 37 The further submissions received on 7 September 2016 from Dr Atkinson also address this point. Mr Dodson confirms that it would be a straight forward matter for a skilled person to test whether a semiconductor device would fall within the scope of the claims of the current application. One would simply need to remove the III-V compound semiconductor material from the nucleation face of the polycrystalline CVD diamond using well established techniques such as etching or polishing and then subject the exposed face (nucleation layer) of the polycrystalline CVD diamond to Raman spectroscopy.
- 38 Taking on board the points raised by Dr Atkinson about the diamond nucleation layer in the device with regards to its Raman spectrum and nucleation density and the explanation provided in the statement by Mr Dodson, I am satisfied that the Raman spectrum characteristics of the device referred to in claim 1 is telling us information about the actual composition of the "diamond" in this important nucleation layer. If the

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<sup>2</sup> J Wagner, C Wild, & P Koldi, "Resonance Effects in Raman Scattering from polycrystalline diamond films", *Appl. Phys. Lett.*, 1991, vol. 59., no. 7, pages 779-781

<sup>3</sup> S Prawer & RJ Nemanich, "Raman Spectroscopy of diamond and doped diamond", *Phil. Trans. R. Soc. Lond. A*, 2004, vol. 362, pages 2537-2565.

amount of sp<sup>3</sup> carbon present in this layer is greater than the amount of sp<sup>2</sup> carbon specified and the nucleation density of the polycrystalline diamond crystals in this layer falls within certain values, and the thermal boundary resistance of this layer is below a certain value, the consequence is a device with improved performance, i.e., has greater power handling properties, component life etc. This Raman characteristic is not some obscure parameter but one that is acknowledged in the art as an appropriate way in which to measure the quality and purity of polycrystalline diamond materials. I have therefore come to the conclusion that defining the device by reference to a Raman spectrum in this particular instance is not a definition by result.

- 39 I am also satisfied from the arguments made by Dr Atkinson and the submissions made by Mr Dodson that verification of a device by destructive testing – i.e., etching or polishing of the semiconductor down to the diamond nucleation layer and examination by Raman and SEM/TEM techniques is something that someone skilled in the fabrication of such semiconductor devices could perform quite readily.
- 40 Furthermore, I am persuaded that there is enough support in the application as filed for the skilled person to arrive at a device with the necessary Raman characteristics and nucleation density at the diamond nucleation layer. I believe this meets the fair entitlement requirement in *Schering Biotech Corp's Application* [1993] RPC 249 (referred to in para 19 above). I find further support for this conclusion in the decision of *David Khan Inc v Conway Stewart & Co Ltd* [1974] RPC 279 at pages 319-320 where it was stated that:

*“A patentee may rightly claim a monopoly wider in extent than what he had invented. If he has discovered a general principle or invented a general method and discloses one way of carrying it out, he may claim all ways of carrying it out, but he is not entitled to claim a monopoly more extensive than is necessary to protect what he has himself said is his invention. He cannot claim all solutions to a problem unless invention lies in identification of the problem”.*

I believe, in this instance, that the applicant has identified a problem with conventionally made semi-conductor devices, namely, the quality of diamond at the diamond nucleation layer. They have linked this to the thermal boundary resistance of the device and found a means to overcome the issue by modifying known techniques for growth of crystalline diamond onto a non-diamond substrate (GaN). By having a more crystalline (sp<sup>3</sup>) diamond nucleation layer (or a less non-diamond carbon (sp<sup>2</sup>) nucleation layer if you will) and combining this feature with the diamond crystals present in the diamond nucleation layer falling in a particular range of nucleation densities, the applicant has demonstrated improved solid state devices can be made as a result.

## **Conclusion**

- 41 Taking account of all of the above, I find that claim 1 and its dependent claims relating to the semiconductor device do not lack clarity under Section 14(5)(c) of the Act.

- 42 Taking account of all of the above, I also find that claim 1 and its dependent claims relating to the semiconductor device do not lack support under Section 14(5)(d) of the Act.
- 43 I therefore remit the current application to the examiner so that the examination process under Section 18 of the Act can be completed.

### **Appeal**

- 44 Any appeal must be lodged within 28 days after the date of this decision.

**Dr L CULLEN**

Deputy Director, acting for the Comptroller