

This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Recent progress in hybrid diamond photonics for quantum information processing and sensing

Corresponding Author: Dr Ryota Katsumi

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

In this paper, Ryota Katsumi et al reviewed recent development of hybrid integration of diamond quantum defects into advanced photonic platforms. Starting from the basic introduction of diamond-based etching and quantum defects creation techniques, they systematically overviewed the state-of-the-art diamond hybrid integration for various quantum technologies. Also, they finally outlooked the future challenges and chances of diamond quantum photonics with heterogeneous photonic chips.

Due to the limitation of diamond heteroepitaxial growth, the hybrid integration of diamond with mature platforms (e.g., Si, SiN, LiNbO₃) is indeed an alternative way to realize scalable and functionalized quantum applications in the near future. Without doubt, this work will therefore raise the readership for specialization in diamond-based photonics and quantum, inspiring future miniature, highly integrated devices. Nevertheless, some questions should be solved before being considered for publication in Communications Engineering.

1. In Section 4, the authors introduced different strategies for diamond hybrid integration. However, the adhesion strength between diamond and hybrid platform is also vital for some further fabrications or manipulations. Commonly, unlike the Van der Waals force of 2D materials, the adhesion force of diamond-hybrid platform interface will be too weak to support their intensive adhesion. Are there any strategies to solve this problem, such as post-annealing?
2. The authors reviewed some techniques for fabricating diamond thin films, such as oxygen plasma thinning and smart cut approach. However, these methods are both time-consuming and limited in size, which will be difficult for scalable production. Hence, will it be suitable to mechanically exfoliate the scalable heterogeneous growth diamond film referring the way of polycrystalline diamond film?
3. The authors mainly introduced diamond photonics based on diamond film, however, will the hybrid integration of diamond nanoparticles with hybrid platforms be another possible way to realize various functions?
4. For future scalable and high-throughput quantum sensing, will it be possible to combine the diamond with microfluidics systems?

Reviewer #2

(Remarks to the Author)

This short review article presents recent progresses in diamond hybrid integration for quantum technologies. The authors give an overview of quantum grade diamond fabrication and diamond nano processing techniques. They present published results in the field of diamond hybrid integration, addressing both quantum information processing and quantum sensing. They finally propose a short conclusion giving very basic challenges and perspectives.

The review is well written and gives a clear, comprehensive, synthetic but not quite exhaustive overview of the field. As such, this review might be useful for non-specialist researchers or engineers. However, to my opinion, it does not provide the community with much insightful thinking or perspectives.

Below are the three main criticisms that could, in my opinion, be addressed to improve significantly the review added value for the community and wider field.

- In general, I find the bibliography quite minimalist and I was surprised to not see for example the work of doi: 10.1109/JLT.2022.3210466, which has been reviewing the field of diamond integrated quantum photonics in 2022. To my opinion, the research works addressing the GaP-on-Diamond approach (from Barclay's group) should be mentioned in this review. Although I recognize this approach is more a heterogeneous strategy than a hybrid one, it does play a role in the development of the field.

- Applications are only briefly mentioned in the review whereas they are really the driving force in the field. To my opinion, the main targeted applications, especially in quantum sensing, should be discussed more deeply, for example within a dedicated section of the review. In fine, applications are setting up the stage for the developments of diamond integrated photonics.
- The review only gives very basic perspectives for the future development of the field. It would be highly appreciable if major challenges, short and long terms, were discussed more in detail in the review. Ideally in the context of applications.

Reviewer #3

(Remarks to the Author)

This review paper presents a comprehensive overview of progress in the application of hybrid photonic devices based on diamond nanostructures incorporating color centers in quantum information processing (QIP) and quantum sensing. The authors first summarize briefly the method of creating color centers in diamond. Then, they emphasize reviewing different fabrication techniques for different types of diamond photonic nanostructure, highlighting their strengths and limitations. Finally, they review various geometry of integrating diamond nanostructures to existing photonic devices, which could attract a wide interest and serve as a useful reference in quantum application and engineering community. Below are my general comments and suggestions:

1. In the review, the authors do not limit their discussion to NV centers in diamond. Instead, they include examples and applications involving group IV vacancies (such as SiV, GeV and SnVs) especially the application in (QIP). Therefore:
 - It would be helpful to summarize the different properties and advantages of both NV centers and group IV vacancies, along with their respective operating or application conditions.
 - Some statement in the manuscript is not universally correct for color centers. For example, the authors state in line 23, "owing to their long spin coherence time at room temperature...", however, group IV vacancies do not exhibit good spin coherence time at room temperature and that's why the most of their applications are at cryogenic temperatures. A brief and clear distinction between NV and group IV vacancies would help readers outside solid-state spin defect communities to understand different color center systems.
2. In the paragraph starting at line 50, the authors discussed the importance of enhancing the PL. It would be beneficial to specify which part of the PL (ZPL, PSB or total PL) are being or should be enhanced for QIP and quantum sensing applications. For instance, in most cases where a cavity is used for QIP, it primarily enhances the ZPL emission which contains indistinguishable photon. Therefore, a brief explanation of how photonic structures are implemented for QIP and quantum sensing would clarify this section.
3. In the section 2A. Ion implantation, for the purpose of incorporating color centers in photonic structures, another very relevant approach that could be included in is using focused ion beam (FIB), which provides a deterministic way of allocating the color centers, for example see: Nat Commun 8, 15376 (2017). Where the method is well established for group IV vacancies. Therefore, including this approach would enhance the context of the review.
4. Also, in the section 2A., another way to create high quality NV centers got recently explored is the carbon implantation, where NV are formed with the native nitrogen in diamond. (see ref: Appl. Phys. Lett. 121, 234001 (2022)). This technique is compatible for photonic structures (mainly Fabry Perot cavities) and worth being discussed.
5. In line 95, the phrase "lateral position derivation" is unclear to me as the horizontal position deviation is discussed above. Here, I assume that it refers to the depth deviation/spread due to the implantation. If this is the case, there is another method I would suggest to include in the discussion is the recently explore delta doping of nitrogen during the CVD growth combined with subsequent carbon implantation. This approach creates a slab of shallow NV within a depth precision of few nanometers. (ref: APL Mater. 11, 021101 (2023)) This method is very relevant for quantum sensing applications and could be included here for completeness.
6. In section 3, the authors summarize different nanofabrication techniques. However, the discussion is often tied to specific structures, which is not necessarily the case. In another word, the fabrication techniques are not generally structure-specific. For example, there are several methods to fabricate a thin film or membrane. At the same time, the functionality of certain structure could be better mentioned. To make it more informative for the reader, a quick summary (potentially with a table) for different photonic structure/geometry with their purpose at the beginning or the end of the section could make it clearer.
7. In the section 3D., another kind of use case for the membrane produced by smart cut technique within the framework of hybrid approaches is to combine it with Fabry-Perot cavities (with DBR mirrors) for example shown in ref: Physical Review B, 99 (16), 165310(2019). This geometry is widely used with NV and SiV and can reach high Q-factor but with a large mode volume. It would be helpful to add into the discussion and compare it with PhC cavities.
8. In the discussion and conclusion, it would be helpful for readers to include a comparison of the performance of diamond based hybrid devices with other quantum platform, and also a comparison between hybrid quantum sensing devices with classical sensors.

Version 1:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

I am satisfied with the revised version. Please publish as it is.

Reviewer #2

(Remarks to the Author)

The authors have addressed in a satisfactory way the comments of the reviewers in the revised version, with substantial added value.

I recommend the publication of this work in Communications Engineering.

Reviewer #3

(Remarks to the Author)

In the revised version, the authors have fully addressed the earlier concerns with the additional explanation and paragraphs. This has made the manuscript now more clear and comprehensive introductory review for the community, suitable for a review in communication engineering.

I recommend the acceptance of the manuscript after addressed two minor comments in the newly added part of the revised manuscript:

1. In the introduction, I thank the authors consideration of my comment and added the specification of the importance of photon enhancement. And in the sentence, "In quantum information processing, a reduction in photon efficiency leads to errors...", I would add a reduction in "coherent" photon efficiency to emphasis.
2. in section 2A the part for group-IV vacancies, the authors wrote, "...thus their spins are insensitive to electric field fluctuations...". I think it is the optical transition (associated with optical dipole) which is insensitive to the electric field instead of spin. Then, the advantage is that the optical coherence is protected by the D3d symmetry.

Open Access This Peer Review File is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

In cases where reviewers are anonymous, credit should be given to 'Anonymous Referee' and the source.

The images or other third party material in this Peer Review File are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons

license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

To view a copy of this license, visit <https://creativecommons.org/licenses/by/4.0/>

Response to Reviewer Comments

Dear Editor and Referees

We thank the editor and reviewers for taking time to review our manuscript, “**Recent progress in hybrid diamond photonics for quantum information processing and sensing**”. The thoughtful comments helped us improve our paper. We have revised the manuscript as per the reviewer’s suggestions, and our pointwise responses to all the comments have been provided below. This response letter includes the original referee comments in *colored bold-italic* text.

Reviewer #1

In this paper, Ryota Katsumi et al reviewed recent development of hybrid integration of diamond quantum defects into advanced photonic platforms. Starting from the basic introduction of diamond-based etching and quantum defects creation techniques, they systematically overviewed the state-of-the-art diamond hybrid integration for various quantum technologies. Also, they finally outlooked the future challenges and chances of diamond quantum photonics with heterogeneous photonic chips.

Due to the limitation of diamond heteroepitaxial growth, the hybrid integration of diamond with mature platforms (e.g., Si, SiN, LiNbO3) is indeed an alternative way to realize scalable and functionalized quantum applications in the near future. Without doubt, this work will therefore raise the readership for specialization in diamond-based photonics and quantum, inspiring future miniature, highly integrated devices. Nevertheless, some questions should be solved before being considered for publication in Communications Engineering.

We thank the referee for the kind summary of our work and provide responses to each of the concerns below.

1. In Section 4, the authors introduced different strategies for diamond hybrid integration. However, the adhesion strength between diamond and hybrid platform is also vital for some further fabrications or manipulations. Commonly, unlike the Van der Waals force of 2D materials, the adhesion force of diamond-hybrid platform interface will be too weak to support their intensive adhesion. Are there any strategies to solve this problem, such as post-annealing?

We appreciate this thoughtful comment. Adhesion for the integration of nanostructured diamond is fine as long as the interface is flat. However, as the reviewer pointed out, the hybrid integration of a diamond membrane onto other materials faces challenges such as poor adhesion and strain. We consider that chemical surface treatment could effectively enhance adhesion. Additionally, post-annealing might further improve adhesion by relieving strain. To follow this comment, we have added sentence in pages 14 in the revised

manuscript as follows:

“This approach may face challenges such as poor adhesion and strain of diamond membranes during the hybrid integration on chip. We consider that chemical surface treatment and post-annealing could effectively enhance adhesion and relieve strain^{137,138}.”

137. Fukumoto S, *et al.* Heterogeneous direct bonding of diamond and semiconductor substrates using NH₃/H₂O₂ cleaning. *Appl Phys Lett* **117**, (2020).

138. Liang J, *et al.* Fabrication of GaN/Diamond Heterointerface and Interfacial Chemical Bonding State for Highly Efficient Device Design. *Adv Mater* **33**, e2104564 (2021).

2. The authors reviewed some techniques for fabricating diamond thin films, such as oxygen plasma thinning and smart cut approach. However, these methods are both time-consuming and limited in size, which will be difficult for scalable production. Hence, will it be suitable to mechanically exfoliate the scalable heterogeneous growth diamond film referring the way of polycrystalline diamond film?

We are grateful for this insightful comment. We agree with the reviewer that oxygen plasma thinning and smart-cut approach pose challenges for scalable production such as their time-consuming and scale-limited processes. One promising solution for these issues would be to refer to the mechanical exfoliation of thin-film polycrystalline diamond membrane. Recent study demonstrated that edge-exposed exfoliation using sticky tape enables mass production of large-area (2-inch wafer), ultrathin (sub-micrometre thickness), ultraflat (sub-nano surface roughness), ultraflexible (360° bendable) and transferrable diamond membranes [J. Jing *et al.*, *Nature* **636**, 627-634 (2024)].

In response to this comment, we have added sentences and references in page 14 as follows:

“It is also noteworthy that thin-film diamond membranes based on the smart-cut approach or oxygen plasma etching present significant challenges for scalable production due to their time-consuming and scale-limited processes. A promising solution to address this issue is inspired by the mechanical exfoliation method for thin-film polycrystalline diamond membranes^{139, 140}. A recent study demonstrated that edge-exposed exfoliation using adhesive tape enables mass production of large-area (2-inch wafer), ultrathin (sub-micrometer thickness), ultraflat (sub-nanometer surface roughness), ultraflexible (360° bendable), and transferrable diamond membranes¹⁴¹.”

139. Yang C, Mi Z, Jin H, Venkatesan T, Vispute R, Bettiol AA. Large-scale fabrication of surface SiV⁻ centers in a flexible diamond membrane. *Carbon* **203**, 842-846 (2023).

140. Xie Y, *et al.* Diamond thin films integrated with flexible substrates and their physical, chemical and biological characteristics. *Journal of Physics D: Applied Physics* **54**, (2021).

141. Jing J, *et al.* Scalable production of ultraflat and ultraflexible diamond membrane. *Nature* **636**, 627-634 (2024).

3. The authors mainly introduced diamond photonics based on diamond film, however, will the hybrid integration of diamond nanoparticles with hybrid platforms be another

possible way to realize various functions?

Thank you for this constructive comment. As the reviewer expects, hybrid integration of diamond nanoparticles on photonic platforms is another promising way to control and integrate quantum emitters on chip. Following this suggestion, we have discussed integration of nanodiamonds on chip in page 18 in the revised manuscript, which is now included as Section 4A.

4. For future scalable and high-throughput quantum sensing, will it be possible to combine the diamond with microfluidics systems?

We consider it possible to combine diamonds with microfluidic systems. This topic is thoroughly reviewed in M. Fujiwara, *Biomicrofluidics* **17**, 054107 (2023).

In response to this comment, we have added sentences and references in page 29 as follows:

“Furthermore, future scalable and high-throughput fabrication of diamond quantum sensors might allow for monitoring electric vehicle batteries²⁵⁴, sensing in microfluidics systems²⁵⁵, and detecting dark matters²⁵⁶. These increasing demands will accelerate the development of truly practical diamond quantum sensors.”

255. Fujiwara M. Diamond quantum sensors in microfluidics technology. *Biomicrofluidics* **17**, 054107 (2023).

Reviewer #2

This short review article presents recent progresses in diamond hybrid integration for quantum technologies. The authors give an overview of quantum grade diamond fabrication and diamond nano processing techniques. They present published results in the field of diamond hybrid integration, addressing both quantum information processing and quantum sensing. They finally propose a short conclusion giving very basic challenges and perspectives.

The review is well written and gives a clear, comprehensive, synthetic but not quite exhaustive overview of the field.

As such, this review might be useful for non-specialist researchers or engineers. However, to my opinion, it does not provide the community with much insightful thinking or perspectives.

Below are the three main criticisms that could, in my opinion, be addressed to improve significantly the review added value for the community and wider field.

We thank the referee for kindly summarizing our work and for providing responses to each of the concerns below. The feedback has helped us to improve the manuscript significantly. Following the revisions, we believe that the manuscript is now well-suited for Communications Engineering, as it aligns closely with the journal's scope and focus.

- In general, I find the bibliography quite minimalist and I was surprised to not see for example the work of doi: 10.1109/JLT.2022.3210466, which has been reviewing the field of diamond integrated quantum photonics in 2022.

To my opinion, the research works addressing the GaP-on-Diamond approach (from Barclay's group) should be mentioned in this review. Although I recognize this approach is more a heterogeneous strategy than a hybrid one, it does play a role in the development of the field.

Thank you for this constructive suggestion. We sincerely apologize for failing to include some important references in our previous manuscript. We have now included the suggested review paper and carefully updated the references in the revised version of the manuscript.

We also agree with the reviewer that GaP-based heterogeneous approach plays an important role in the development of quantum photonics. In response to this comment, we have incorporated a discussion on the GaP-on-Diamond approach in the revised manuscript, now included as Section 4B.

- Applications are only briefly mentioned in the review whereas they are really the driving force in the field. To my opinion, the main targeted applications, especially in quantum sensing, should be discussed more deeply, for example within a dedicated section of the review. In fine, applications are setting up the stage for the

developments of diamond integrated photonics.

Thank you for highlighting the importance of applications in driving the field. We completely agree with the reviewer that applications, particularly in quantum sensing, play a crucial role in shaping the development of integrated diamond photonics. In response to your suggestion, we have added a dedicated section in the revised manuscript to discuss the main targeted applications in greater depth, which is now included as Section 2A.

- The review only gives very basic perspectives for the future development of the field. It would be highly appreciable if major challenges, short and long terms, were discussed more in detail in the review. Ideally in the context of applications.

Thank you for your valuable feedback. We appreciate your suggestion and agree that discussing the major challenges, both short-term and long-term, in more detail would add significant value to the review. In the revised manuscript, we have expanded this discussion and placed it in the context of practical applications to provide a more comprehensive perspective on the future development of the field, which is now included in Section 6.

Reviewer #3

This review paper presents a comprehensive overview of progress in the application of hybrid photonic devices based on diamond nanostructures incorporating color centers in quantum information processing (QIP) and quantum sensing. The authors first summarize briefly the method of creating color centers in diamond. Then, they emphasize reviewing different fabrication techniques for different types of diamond photonic nanostructure, highlighting their strengths and limitations. Finally, they review various geometry of integrating diamond nanostructures to existing photonic devices, which could attract a wide interest and serve as a useful reference in quantum application and engineering community. Below are my general comments and suggestions:

We thank the reviewer for the kind summary of our work and provide responses to each of the concerns inline below.

1. In the review, the authors do not limit their discussion to NV centers in diamond. Instead, they include examples and applications involving group IV vacancies (such as SiV, GeV and SnVs) especially the application in (QIP). Therefore:

- It would be helpful to summarize the different properties and advantages of both NV centers and group IV vacancies, along with their respective operating or application conditions.*

- Some statement in the manuscript is not universally correct for color centers. For example, the authors state in line 23, "owing to their long spin coherence time at room temperature...", however, group IV vacancies do not exhibit good spin coherence time at room temperature and that's why the most of their applications are at cryogenic temperatures. A brief and clear distinction between NV and group IV vacancies would help readers outside solid-state spin defect communities to understand different color center systems.*

We appreciate this constructive suggestion and apologize for any confusion caused to the reviewer in some of the descriptions regarding color centers. In response to this feedback, we have added a section summarizing the differences in properties, application conditions, and advantages of both NV centers and group-IV vacancies, which is now included as Section 2A.

2. In the paragraph starting at line 50, the authors discussed the importance of enhancing the PL. It would be beneficial to specify which part of the PL (ZPL, PSB or total PL) are being or should be enhanced for QIP and quantum sensing applications. For instance, in most cases where a cavity is used for QIP, it primarily enhances the ZPL emission which contains indistinguishable photon. Therefore, a brief explanation

of how photonic structures are implemented for QIP and quantum sensing would clarify this section.

Thank you for this thoughtful suggestion. We agree with the reviewer that it is important to specify which part of the PL (ZPL, PSB, or total PL) is enhanced for each quantum application. In response to this comment, we have added a sentence in page 3 in the revised manuscript as follows:

“For quantum information processing and quantum sensing, the number of photons in the zero-phonon line (ZPL) and the total number of photons are, respectively, of great importance for practical applications. In quantum information processing, a reduction in photon efficiency leads to errors of computations and low entanglement rates^{30,31,32}. For quantum sensing, the field sensitivity is degraded by a decrease in collected amount of NV photons³.”

3. In the section 2A. Ion implantation, for the purpose of incorporating color centers in photonic structures, another very relevant approach that could be included in is using focused ion beam (FIB), which provides a deterministic way of allocating the color centers, for example see: Nat Commun 8, 15376 (2017). Where the method is well established for group IV vacancies. Therefore, including this approach would enhance the context of the review.

We appreciate this constructive suggestion and agree with the reviewer that including the FIB approach enhances the context of the review. In response to this comment, we have updated Section 2B and references as follows:

“Another promising approach is based on a focused ion beam, which can create single color center without mask structures^{80, 81, 82, 83}. For both approaches, the lateral positional derivation is better than 30 nm. Meanwhile, these approaches have a relatively low yield; the reported yield for creating NV (SiV) centers using ion implantation (focused ion beam) is approximately 25%⁷⁹ (20%)⁸².”

80. Lesik M, *et al.* Maskless and targeted creation of arrays of colour centres in diamond using focused ion beam technology. *physica status solidi (a)* **210**, 2055-2059 (2013).

81. Tamura S, *et al.* Array of bright silicon-vacancy centers in diamond fabricated by low-energy focused ion beam implantation. *Applied Physics Express* **7**, 115201 (2014).

82. Schroder T, *et al.* Scalable focused ion beam creation of nearly lifetime-limited single quantum emitters in diamond nanostructures. *Nat Commun* **8**, 15376 (2017).

83. Höflich K, *et al.* Roadmap for focused ion beam technologies. *Applied Physics Reviews* **10**, 041311 (2023).

4. Also, in the section 2A., another way to create high quality NV centers got recently explored is the carbon implantation, where NV are formed with the native nitrogen in diamond. (see ref: Appl. Phys. Lett. 121, 234001 (2022)). This technique is compatible for photonic structures (mainly Fabry Perot cavities) and worth being discussed.

We appreciate this valuable comment. In response to this comment, we have added the

suggested reference in the manuscript. We have also included the discussion of Fabry P rot cavity in Section 3D.

5. In line 95, the phrase "lateral position derivation" is unclear to me as the horizontal position deviation is discussed above. Here, I assume that it refers to the depth deviation/spread due to the implantation. If this is the case, there is another method I would suggest to include in the discussion is the recently explore delta doping of nitrogen during the CVD growth combined with subsequent carbon implantation. This approach creates a slab of shallow NV within a depth precision of few nanometers. (ref: APL Mater. 11, 021101 (2023)) This method is very relevant for quantum sensing applications and could be included here for completeness.

Thank you for this constructive suggestion and we apologize for confusing the reviewer. As the reviewer pointed out, lateral position derivation is not a correct expression. To clarify the definition, we have modified the wording in page 10 in the manuscript. We have also included the references including the suggested paper in the revised manuscript as follows:

- 87. Ohno K, *et al.* Engineering shallow spins in diamond with nitrogen delta-doping. *Appl Phys Lett* **101**, (2012).
- 88. Lee JC, *et al.* Deterministic coupling of delta-doped nitrogen vacancy centers to a nanobeam photonic crystal cavity. *Appl Phys Lett* **105**, (2014).
- 89. Jaffe T, *et al.* Novel Ultra Localized and Dense Nitrogen Delta-Doping in Diamond for Advanced Quantum Sensing. *Nano Lett* **20**, 3192-3198 (2020)
- 90. Bogdanov SA, *et al.* Optical investigation of as-grown NV centers in heavily nitrogen doped delta layers in CVD diamond. *Materials Today Communications* **24**, (2020).
- 91. Hughes LB, *et al.* Two-dimensional spin systems in PECVD-grown diamond with tunable density and long coherence for enhanced quantum sensing and simulation. *APL Materials* **11**, (2023).

6. In section 3, the authors summarize different nanofabrication techniques. However, the discussion is often tied to specific structures, which is not necessarily the case. In another word, the fabrication techniques are not generally structure-specific. For example, there are several methods to fabricate a thin film or membrane. At the same time, the functionality of certain structure could be better mentioned. To make it more informative for the reader, a quick summary (potentially with a table) for different photonic structure/geometry with their purpose at the beginning or the end of the section could make it clearer.

We agree with the reviewer that a brief summary of photonic structures will make Section 3 clearer for readers. In response to this comment, we have incorporated a summary of diamond photonic structures in the revised manuscript, now included as Section 3E with Table 1.

7. In the section 3D., another kind of use case for the membrane produced by smart cut technique within the framework of hybrid approaches is to combine it with Fabry-Perot cavities (with DBR mirrors) for example shown in ref: Physical Review B, 99 (16),

165310(2019). This geometry is widely used with NV and SiV and can reach high Q-factor but with a large mode volume. It would be helpful to add into the discussion and compare it with PhC cavities.

We thank the reviewer for this constructive comment. In response to this comment, we have included the discussion of miniaturized Fabry-Pérot microcavities in Section 3D in the revised manuscript.

8. In the discussion and conclusion, it would be helpful for readers to include a comparison of the performance of diamond based hybrid devices with other quantum platform, and also a comparison between hybrid quantum sensing devices with classical sensors.

Thank you for your insightful suggestion. We agree that including a comparison of the performance of diamond-based hybrid quantum devices with other quantum platforms, as well as a comparison between hybrid quantum sensing devices and classical sensors, would provide valuable context for readers. In response, we have incorporated these comparisons in the revised manuscript, now included as Tables 2 and 3. This addition aims to highlight the unique advantages and potential limitations of diamond-based hybrid devices in relation to alternative technologies, offering a more comprehensive understanding of their role in the broader landscape of quantum and classical sensing platforms.

Finally, we again thank the reviewers for providing valuable comments on our manuscript. We believe that the revised paper is more convincing and valuable for readers of Communications Engineering.

Sincerely yours,

Ryota Katsumi

Visiting Professor
Department of Electrical Engineering
Columbia University
530 West 120th Street · New York, NY 10027
Phone: +1-656-449-6415
E-mail: rk3339@columbia.edu

Response to Reviewer Comments

Dear Editor and Referees

We again thank the editor and reviewers for taking time to review our manuscript, “**Recent progress in hybrid diamond photonics for quantum information processing and sensing**”. The thoughtful comments helped us improve our paper. We have revised the manuscript as per the reviewer’s suggestions, and our pointwise responses to all the comments have been provided below. This response letter includes the original referee comments in *colored bold-italic* text.

Reviewer #1

I am satisfied with the revised version. Please publish as it is.

We sincerely appreciate the referee's time and effort in reviewing our manuscript and recommending its publication.

Reviewer #2

The authors have addressed in a satisfactory way the comments of the reviewers in the revised version, with substantial added value.

I recommend the publication of this work in Communications Engineering.

We thank the reviewer for the time and effort in reviewing our manuscript and the recommendation for its publication.

Reviewer #3

In the revised version, the authors have fully addressed the earlier concerns with the additional explanation and paragraphs. This has made the manuscript now more clear and comprehensive introductory review for the community, suitable for a review in communication engineering.

I recommend the acceptance of the manuscript after addressed two minor comments in the newly added part of the revised manuscript:

We sincerely appreciate your thorough review and your recommendation for acceptance.

1. In the introduction, I thank the authors consideration of my comment and added the specification of the importance of photon enhancement. And in the sentence, "In quantum information processing, a reduction in photon efficiency leads to errors...", I

would add a reduction in "coherent" photon efficiency to emphasise.

Thank you for this constructive suggestion. Following this comment, we have revised this sentence as follows:

"For quantum information processing and quantum sensing, the number of photons in the zero-phonon line (ZPL) and the total number of photons are, respectively, of great importance for practical applications. In quantum information processing, a reduction in **coherent** photon efficiency leads to errors of computations and low entanglement rates."

2. in section 2A the part for group-IV vacancies, the authors wrote, "...thus their spins are insensitive to electric field fluctuations...". I think it is the optical transition (associated with optical dipole) which is insensitive to the electric field instead of spin. Then, the advantage is that the optical coherence is protected by the D_{3d} symmetry.

We thank the reviewer for pointing out this. As the reviewer points out, the advantage of group-IV vacancies is the optical coherence protected by D_{3d} symmetry.

In response to this comment, we have revised this sentence as follows:

"The inversion-symmetric D_{3d} structure of the defect (Fig. 3a) also results in no permanent electric dipole, **making the optical transition insensitive to electric field fluctuations and thereby protecting the optical coherence.**"

Finally, we again thank the reviewers for providing valuable comments on our revised manuscript. We believe that the revised paper is more convincing and valuable for readers of Communications Engineering.

Sincerely yours,

Ryota Katsumi

Visiting Professor
Department of Electrical Engineering
Columbia University
530 West 120th Street · New York, NY 10027
Phone: +1-656-449-6415
E-mail: rk3339@columbia.edu