Review of the doctoral dissertation "InAs/InP quantum dots for telecom quantum photonics",

by Pawel Holewa.

Overall relevance and originality of the doctoral work:

Overall, this study demonstrated a promising photonic integration platform, encompassing epitaxial growth and nanofabrication, for the creation of triggered sources of single-photons in the C-band. C-band single-photons are highly desirable for quantum networks and secure quantum communications because of the low optical fiber propagation losses observed in the 3rd telecom window. Because amplification is not possible in this context, propagation losses crucially determine not only the reach of a link (e.g. between quantum repeaters), but also the rates at which information can be transferred. In my view the candidate's doctoral work follows a consistent, logical and holistic progression from material growth to deterministic device fabrication, and has produced a number of relevant and novel contributions of technological and scientific importance.

In particular, the candidate had a significant contribution in demonstration, for the first time:

1 – Low-density growth of InAs/InP quantum dots by MOVPE, which is critical for fabrication of devices with functionality based on single quantum dots emitting at telecom wavelengths. This is a material system that offers advantages over others being investigated for the same objective, and low QD density growth had not been demonstrated previously.

2 – Symmetric InAs/(In,Al,Ga)As/InP quantum dots by "ripening" in MBE, in an effort to grow symmetric quantum dots emitting in the telecom C-band, the optical properties of which had not been extensively characterized previously. One notable contribution is the discovery and description long-range ordering of the crystal lattice, which had not been done previously.

3 – Symmetric InAs/InP quantum dots by Droplet Epitaxy in MOVPE. This is a promising method grow low-density InAs/InP QDs with high in-plane symmetry QDs. The relevance of this pursuit is that QDs with high symmetry can be used as sources of polarization-entangled photons pairs, produced from the radiative biexciton-exciton cascade, provided that the X fine-structure splitting is (ideally) zero. Such a feature is very challenging to realize with the more widespread S-K growth mode. Optimization of the growth process in MOVPE allowed the candidate to achieve a number of important milestones, such as sufficiently low density, emission close to the center of the C-band, single-photon purity for observed single quantum dots, and some potential for entangled-photon pair generation.

4 - Heterogeneous integration of self-assembled InAs/InP quantum dots onto a silicon /metallic reflector substrate. Though this type of heterogeneous integration based on adhesive bonding had already been demonstrated for the GaAs/InAs and GaAs/AlGaAs quantum dots for NIR or O-band telecom emission, here it was applied to the InP/InAs quantum dot case, which produce telecom C-band single-photons. Importantly, introduction of the integrated metallic mirror led to the enhanced photon extraction that was demonstrated for an unetched sample, which enables high throughput, deterministic fabrication of single QD devices. This is an important technological contribution, which culminated in the work reported in Article #5.

5 - Deterministic fabrication of devices containing single InAs quantum dots to InP photonic nanostructures is possible through wide-field photoluminescence imaging. This method is advantageous over other mainstream methods (e.g., confocal scanning microscopy) in that it offers high throughput, which is important for device scalability in device fabrication. Wide-field imaging of single quantum emitters is very challenging at telecom wavelengths because telecom wavelength imaging sensors available commercially to date feature overwhelming noise levels. The present work shows that this issue can be circumvented with a heterogeneous wafer-bonded material stack, which, offering a relatively high photon extraction efficiency, leads to reasonable signal-to-noise levels in imaging, sufficient for localization of single quantum dots. To my knowledge this is first time such capability is demonstrated for C-band quantum dots.

In view of the above, it is my opinion that the doctoral dissertation presents original and very promising solutions to technological development for the field of quantum information.

Furthermore, the breadth of the work done and reported in the dissertation, the clarity of dissertation text, the soundness of the reported results and high quality of publications that were led by the candidate demonstrate his solid, general theoretical knowledge in materials science, solid-state physics, optics and quantum photonics, as well as his ability to independently conduct impactful scientific work.

I believe his concerted, multidisciplinary effort (from material growth to measurement) towards creating a photonic integration platform that may allow the deterministic creation of integrated quantum photonic devices based on single quantum emitters at telecom C-band wavelengths a consequential achievement, with great potential for the development of photonic quantum technologies.

For these reasons, I recommend awarding the doctoral degree to Pawel Holewa, with highest distinction.

Marcelo Davanco, National Institute of Standards and Technology, USA

July 27, 2023

Review of the Dissertation and Articles:

The dissertation is composed of four sections in its Part I - Introduction, which cover basics of all topics associated with the research described in the five articles produced by the candidate, included in Part II - Core Publications. Below is a brief description of each of the four chapters, with comments.

I have made number of suggestions below for the improvement of the dissertation. The main text is in black, major and **minor** comments are in red and **blue** respectively

Part I - Introduction

Chapter 1 – Motivation

This chapter motivates the overall research work step-by-step, starting from the need for telecom single-photon sources for photonic quantum information, then briefly covering methods (spontaneous parametric generation, quantum emitters) and solid-state quantum emitter material systems (rare-earths, carbon nanotube defects, TMDs), which are argued to be, respectively, fundamentally limited in signal brightness and purity, and less technologically mature than epitaxial quantum dots. Section 1.2 provides a brief history of quantum dot development towards quantum information, and aptly makes the case for the superior maturity of this class of quantum emitters. The historical perspective includes subsections on the development of C-band quantum dots, the development of which is much more recent than those featuring emission at shorter wavelengths. The two material systems (InAs/GaAs on metamorphic InGaAs layers or InAs/InP) that have produced more significant results in terms of quantum photonics are describe in some detail, and good account of achievements is provided. The growth methods for InAs/InP QD growth explored in the candidate's PhD work (Low-density Stanski-Krastanov growth in MOVPE, **Article #1**, MOVPE droplet epitaxy, **Article #3,** and ripening in MBE, **Article #2**), are briefly introduced with a reasonable amount of detail.

The problem of single-photon extraction from as-grown quantum dot material is covered in Section 1.3, starting with a reasonable motivation, and covering some important aspects of solving the problem for the InAs/InP system in particular. Following the initial discussion, a subsection on moderately-broad cavities and circular Bragg gratings follow where the need for such class of cavities is motivated, tending towards application in entangled photo-pair sources, and a brief comparison with alternative nanophotonic geometries for the same purpose are presented. This discussion is followed by a subsection that comments on brightness enhancement geometries employed so far for telecom quantum dots by the leading research groups, and motivates the choice for the metal-backed circular Bragg grating that was demonstrated in **Article #5**, based on the hybrid, wafer-bonded stack demonstrated in **Article #4.**

Comment #1 (minor): **On page 8, there is a comment about using narrow-band Purcell factor for enhancing the \eta. I think this possibility is a bit nuanced and could be expanded in a more informative way. The Purcell enhancement Fp helps the efficiency \eta, but there's a non-straightforward trade-off between \eta and Fp that needs to be addressed. In particular, if you can**

suppress QD coupling to useless spatial modes (e.g., which are not collected efficiently by your collection optic), you don't need Purcell to be high at all. See e.g., nanowires from Jean-Michel Gerard (or our suspended nanowaveguides: APL 99 121101 (2011). Other good places to look at ACS Photonics 2023, 10, 4, 959–967, or Phys. Rev. Lett. 129, 05360 (see the SI in particular).

The need for single QD positioning for the deterministic fabrication of single QD devices is motivated next, and is followed by a description of currently used techniques. The main techniques, named "Scanning in-situ" and "Photoluminescence imaging" are briefly described and comment with reasonable detail.

Comment #2 (minor): In the "Scanning in-situ" method description, I feel that there are two distinct aspects that are involved in the various citations provided here, that differentiates them and should be better highlighted in the text:
1 –Scanning-based imaging techniques for finding single QDs (AFM, SEM, CL, confocal PL)
2 – Lithography, which can be ex situ (e-ebeam, confocal optical) or ex situ (e-beam lithography).
Also, "in situ" should not be hyphenated.

The Photoluminescence imaging technique, used in Article 5, is next discussed with good detail, and highlights the advantage in terms of scalability in fabrication that is inherent to the technique (in comparison with the "Scanning in-situ" techniques. I find the last subsection, on challenges involved in Telecom imaging for single QD positioning to be very interesting and very helpful, particularly for other (dim) types of telecom quantum emitters.

Comment #3 (minor): Reference [143] has similar work as demonstrated in Article 5, involving deterministic fabrication of a circular Bragg grating with a deterministically positioned O-band QD. The authors there used the same type of Photoluminescence imaging-based QD positioning technique as here. I think the differences between the two systems should be expanded, to further emphasize the innovation aspect of the research, going beyond the type of QD and the wavelength range. In particular, ref. [143] uses a LN2 cooled InGaAs camera, which is quite expensive and cumbersome, however probably could work just fine for non metal-mirror-backed QDs. The fact that in the present case imaging is possible with a (considerably cheaper, more compact, less cumbersome and, especially, noisier) camera is of great practical appeal.

Chapter 2 – Theory

This chapter briefly covers fundamental theory for understanding of all the work that was performed, including:

Sections 2.1 and 2.2: MOVPE and growth of epitaxial QDs:

This section provides an introduction to the growth technique as well as a historical perspective. The key processes driving growth are explained (thermodynamics, kinectics and heat transport, surface processes and chemical reactions) and basic theory that explains and motivates growth strategies is provided. A subsection describes equilibrium theory of epitaxy used with the main QD growth modes used nowadays (S-K, F-M and V-W), starting thermodynamics and kinetics arguments, and the S-K and droplet epitaxy modes, investigated in Papers #1-#3, are detailed further in separate subsections, where parameters and strategies for optimizing growth conditions are covered in good detail.

As a non-specialist I find the amount and quality of the information to be quite good, and appreciate the candidate's effort in making the explanations didactic.

Comment #4 (major): The candidate makes a comment at the top of page 17 that sounds very negative regarding the ability to understand growth MOVPE growth processes. One gets a sense that the models developed to describe growth are hopelessly insufficient, and are likely remain so. Is it the case that the growth process must generally regarded as a black box, as suggested by the text? Similarly on page 22, where it is stated that "determining rate constants correctly is impossible" for any specific reactor. What is the way around it? Also relatedly, in the comment on page 22 there is a comment that "the assumption that the growth can be understood as a superposition of individual pyrolysis reactions, which was an initial approach to the MOVPE growth, is no longer expected to be relevant for the actual growth reactions." What is the current understading?

Comment #5 (minor): What is 'B' in Figure 25? I suggest defining in the caption itself at least.

Comment #6 (major): In the discussion of droplet epitaxy starting on page 27, I would say that a big disadvantage of the S-K mode is the wide ensemble inhomogeneous broadening (several tens of nm), which makes it hard to find two dots with the same spectrum in low QD density wafers. I think droplet epitaxy has an advantage there (or, at least the local droplet etching technique gives GaAs dots with spectral spread of <= 10 nm). It goes without saying that lack of spatial control of individual QDs is a big problem as well (which nonetheless can be solved with e.g., the PL imaging technique used by the candidate).

Comment #7(minor): In the discussing the selection rules for the dark exciton on page 36, it is mentioned that the total photon angular momentum is 1, which precludes transitions involving excitons with total angular momentum projection with |M|=2. Such excitons are therefore dark. What about photons of total angular momentum different than 1, e.g., in vortex beams?

Section 2.3: Physics of QD-confined excitons

This section starts with brief, basic information about spatial charge confinement in 1D wells, and is followed by a description of single particle calculation methods used for determination of the QD single-carrier wavefunctions and energy levels. The continuum and atomistic pseudopotential methods are briefly introduced, and relevant aspects are outlined. In particular, the eight-band k.p method is introduced, which is very important for understanding III-V semiconductor band structure (including QWs and QDs), and is applied to support experimental QD characterization in Paper #1 (which focuses on QD growth). The construction of exciton wavefunctions is discussed next, considering Coulomb interaction energies between single particles, and based on Hartree-Fock theory. Both Configuration and Exchange Interaction components are explained with sufficient detail. Interaction with light fields and transition selection rules are covered next, and summarized in a convenient way. In particular, a description of the expected transition energies with respect to each other and their polarizations is provided, which is very helpful for exciton species identification in experiments.

Comment #8 (minor): While the information provided in the text is of good practical utility, I think it would be beneficial for general readers to have a brief, intuitive explanation of the physical meaning of direct and exchange coulomb interactions in Section 2.3. It would make the text more self-contained.

Section 2.4: Quantum optics concepts and experiments

This section introduces quantum optics techniques for the characterization of quantum light sources regarding photon statistics. These techniques are used for characterization of fabricated devices in Papers #3 and 4. The primary focus is on the second-order correlations and the Hanbury-Brown and Twiss configuration. I think the information provided is adequate, though a lot more could be written about experimental caveats that could be extremely valuable for readers, for instance relating to the use of start-stop time intervals for approximating g(2) and its proper normalization, presence of a Poissonian background, timing jitter limitations. The Hong-Ou-Mandel technique is also not included. Many of these experimental details have been described in reasonable detail in Papers #4 and 5.

Comment #9 (minor): I suggest at least mentioning the various different experimental imperfections that affect extraction of g(2), and how to deal with them. There are quite a number of papers and other documents that could be cited (e.g. *). Also, I think a brief introduction to the Hong-Ou-Mandel experiment would be very welcome as well, since it is used in Paper #5 and is actually an important measurement for determining one of the most relevant properties of single-photon sources.**

Section 2.5: Cavity QED effects.

This Section provides basic theory on Cavity Quantum Electrodynamics, which can be leveraged for enhancing the interaction of light with the quantum dots and in particular engineering single-photon sources via nanophotonics. The Section starts with theory of Fabry-Perot cavities which, even if idealized in the context of nanophotonics, covers all the relevant physics, and in an intuitive way. Emitter-cavity coupling is then analyzed next, and good emphasis is given to the relevant parameters, such as the coupling strength, cavity outcoupling rates, emitter decay rate, etc. This makes the text very convenient from a practical standpoint. In particular, Box 6 has a nice summary of requires for maximizing the cavity-emitter coupling in the weak-coupling regime

Comment #10 (minor): For single-photon sources, the outcoupling efficiency *into a desirable mode* is the most relevant parameter, which involves some ability to mode-match the cavity emission to the spatial modes supported by the collection optic (e.g., an optical fiber mode). This concept is taken for granted many times (e.g. one can get high Fp and high beta to a cavity mode that outcouples into a weird vortex beam), and so I suggest expanding on this in the text. See Comment #1 above. Another important point to mention is the need to balance Fp and outcoupling rate k in order to maximize the

source efficiency. See Comment #1 above, and especially the SI in Knall et al., Phys. Rev. Lett. 129, 05360.

Chapter 3 – Experimental Methods

Experimental methods used in the research reported in Articles #1 to 5 are described in this Chapter. There are two Sections, regarding fabrication and optical characterization.

Section 3.1, on fabrication, covers:

- Epitaxial QD growth in MOVPE, including a reasonably detailed explanation of the reactor, the various degrees of freedom for parameter tuning during QD growth. This is very important since one of the main objectives of the research program was to obtain reasonably low-density QD growth (demonstrated in Article #1). There is considerable detail about the growth procedure, which is generally desirable.
- Processing of grown QD wafers, with techniques that were used for results reported in Articles #4 and #5. This includes adhesive bonding (first used and reported in Article #4) and electron-beam lithography and InP etching (mostly used in article #5). Deterministic positioning is also briefly introduced, though not with considerable detail. This is left for the SI of Article #5.
- A full single QD device process flow is provided, including necessary characterization steps that go beyond traditional optoelectronic device process flows. This diagram is very informative and a welcome addition to the dissertation.

Section 3.2, on optical characterization of the quantum dots and devices. This includes:

- Photoluminescence setup and techniques for excitonic species identification, which include accounting for the expected energy separations, based on described theory, second-order correlation measurements, between the different observed lines. Characterization of the linear degree of polarization of the emission is also described.
- Imaging setup, including a reasonably detailed description of the setup and QD localization (though most details about the latter are left to the SI of Article #5).
- Time-resolved PL and correlation spectroscopy
- Calibration of the setup for determination of single-photon extraction efficiency
- Determination of single-photon purity

Comment #11 (minor): Excitonic species identification by photoluminescence power series is not commented upon. While this was described with good detail in the theory part, a comment about the experiment seems to be missing. In particular, it would be useful to hear account of how the techniques are used, individually or complementarily, to identify e.g. the C, CC and CX lines, reliability (e.g., how often are the expected power laws for the PL as a function of pump power observed?), etc.

Comment #12 (major): In Article #5, it seems the maximum experimental collection efficiency of 16.6 % is considerably lower than the expected from simulations. Since QD positioning has a strong impact on the extraction efficiency, it would be helpful to discuss the validity of gauging the achieved QD positioning precision with device performance. A related, helpful discussion is related to aberrations in the optical systems, that may lead to large errors in positioning, see e.g. Copeland et al., arXiv.2106.10221, which was not covered in the text.

Comment #13 (minor): Considering that the one of the most important aspects of single-photon sources for quantum information is the photon indistinguishability, I think experimental methods used to characterize it (e.g., via a Hong-Ou-Mandel experiment, or indirectly via spectroscopic measurements) are conspicuously missing from Part I of the dissertation.

Comment # 14 (minor): Even though resonant or LA-phonon of the QD have not been performed in experiments reported in the published articles, they are important techniques that favor single-photon indistinguishability. I think at least a brief comment should be included in the main text.

Chapter 4 – Summary of results

This Section summarizes each one of the Articles that follow.

Part II – Published and submitted articles

Article #1: P. HOLEWA et al., Optical and electronic properties of low-density InAs/InP quantum dot-like structures devoted to single-photon emitters at telecom wavelengths, Physical Review B, 101, 19 (2020).

This article reported on an investigation of MOVPE growth of S-K InAs/InP quantum dots at low densities, which is critical for fabrication of devices with functionality based on single quantum dots emitting at telecom wavelengths. Optimal conditions were developed, based on experimental characterization of optical and electronic properties of grown samples. My understanding is that the candidate did not perform the growth, however researched and performed photoluminescence experiments, and also analyzed and interpreted the data.

Overall, this is a contribution of high technological importance, because this is a material system that offers advantages over others being investigated for the same objective, and low QD density growth had not been demonstrated previously. In particular, results from this initial investigation were later used for device work carried out and reported in Articles #4 and Article #5.

The investigation includes interpretation of temperature-dependent photoluminescence and time-resolved PL measurements of QD ensembles, revealing spectral features that were analyzed based existing theoretical models, which provide good support for conclusions regarding energy level structure of the QD excitons.

The candidate's contributions to this paper were:

- PL experiments for the investigated QDs, observation of QD families.
- Research of techniques to be used to explain the measured data:

    - Temperature-, excitation-power dependent PL, polarization-resolved PL, time-resolved PL, PL excitation spectroscopy
    - 8-band $k{\cdot}p$ calculations of the WL states
    - Initial investigations of QD single-particle states
- Analysis of all PL, PLE, TRPL and µPL experimental data, interpretation of results.
- Preparation of the manuscript and response to reviews.

Article #2: P. HOLEWA, et al., Optical and Electronic Properties of Symmetric InAs/(In,Al,Ga)As/InP Quantum Dots Formed by Ripening in Molecular Beam Epitaxy: A Potential System for Broad-Range Single-Photon Telecom Emitters, Physical Review Applied, 14, 6 (2020).

This article covered MBE-growth of InAs/(In,Al,Ga)As/InP Quantum Dots via the "ripening" technique. The relevance of this approach is that the technique produced highly in-plane symmetric QDs emitting in the telecom C-band. The candidate reports here for the first time in my understanding a comprehensive characterization of the optical properties of the grown QDs. One notable contribution of this article was the first discovery and description long-range ordering of the crystal lattice for QDs. Conclusions were based on comparison of spectroscopic observations and modeling with an 8-band $k{\cdot}p$ approach, from pre-existing software. This result is of both scientific and technological relevance.

The candidate's contributions to this article were:

- PL studies for the QD ensemble in a wide spectral range, observation of the QD families
- Research to explain the origin of the observed results:
    - Modeling their electronic structure using the 8-band $k{\cdot}p$ method.
    - Discovery and description of the first long-range ordering of the crystal lattice in the case of QDs.
- Spectroscopy
    - temperature-dependent, polarization-resolved, power-dependent, and time-resolved PL
- Interpretation of the obtained results
- Analysis of all experimental data
- Preparation of the manuscript, response to the reviews.

Article #3: P. HOLEWA, et al., Droplet epitaxy symmetric InAs/InP quantum dots for quantum emission in the third telecom window: morphology, optical and electronic properties, Nanophotonics, 11, 8 (2022).

This article reports on a novel low-density droplet epitaxy method for growing InAs/InP QDs with potential to achieving high in-plane symmetry QDs. The relevance of this pursuit is that QDs with high symmetry can be used as sources of polarization-entangled photons pairs, produced from the radiative biexciton-exciton cascade, provided that the X fine-structure splitting is (ideally) zero. Such a feature is very challenging to realize with the more widespread S-K growth mode. Optimization of the growth process in MOVPE allowed the candidate to achieve a number of important milestones, such as sufficiently low density, emission close to the center of the C-band, single-photon purity for observed single quantum dots, and some potential for entangled-photon pair generation as descried above.

While measurement of QD ensemble micro-PL indicated near zero neutral exciton fine-structure splitting, a relatively large FSS of 50 uEv was observed for a single QD on a mesa, blamed on sample processing. So there is some reasonable promise that the technique can produced suitable QDs for entangled photon-pair generation, however further studies are still needed to verify that (and optimize growth conditions further). I find that this article is a relevant technical contribution, in the sense that it demonstrates a reasonable promise for the new growth process in a new material platform.

The candidates' contributions were:

- Optimization of the QD growth method and the growth of QDs, AFM
- Measurements:
    - PL and μPL, identification and study of exciton complexes,
    - Correlation and time-resolved
- Interpretation of the obtained results
- Analysis of all experimental data
- Preparation of the manuscript, response to the reviews. The candidate was a corresponding author.

Article #4: Holewa at al., Bright Quantum Dot Single-Photon Emitters at Telecom Bands Heterogeneously Integrated with Si, ACS Photonics, 9, 7 (2022).

In this article, the candidate demonstrated for the first time heterogeneous integration of self-assembled InAs/InP quantum dots onto a silicon /metallic reflector substrate. Though this type of heterogeneous integration based on adhesive bonding had already been demonstrated for the GaAs/InAs and GaAs/AlGaAs quantum dots for NIR or O-band telecom emission, here it was applied to the InP/InAs quantum dot case, which produce telecom C-band single-photons. Importantly, introduction of the integrated metallic mirror led to the enhanced photon extraction that was demonstrated for an unetched sample, which, as demonstrated for the first time in Article #5, allows such wafers to be analyzed in a wide-field PL imaging setup for single QD localization, enabling high throughput, deterministic fabrication of single QD devices. For this reason, this article consists of an important technological contribution, as an initial step to Article #5.

The contributions of candidate to this article were:

- Optimization of the S-K QD growth and the growth of the QDs use for fabrication
- Participation in the design of the structure,
- Fabrication of wafer bonded samples
- Optical characterization in μPL
    - Identification and study of exciton complexes in temperature-, power-dependent and polarization resolved μPL, correlation spectroscopy, determination of photon extraction efficiency
- Data analysis and interpretation

- Preparation of the manuscript and response to review. The candidate was a corresponding author.

Article #5: P. HOLEWA, et al., Scalable quantum photonic devices emitting indistinguishable photons in the telecom C-band, arXiv:2304.02515 (pre-print)

This article pre-print reports on a technique that for the first time allowed deterministic fabrication of nanophotonic devices containing single epitaxial InP/InAs quantum dots, capable of providing C-band telecom single-photon emission. The fabrication method employs a wide-field single QD micro-photoluminescence imaging technique which allows in principle a high throughput for the localization of single QDs, in comparison e.g., with confocal scanning microscopy.

One crucial aspect of the work is in the use of wide-field imaging of QDs at telecom wavelengths is shown to be possible with a TE-cooled camera. This was made possible by a relatively high QD light extraction efficiency from the semiconductor, achieved in samples where the QD-hosting InP film is placed above a metallic mirror via an adhesive wafer bonding method, described in Article #4. Demonstrating the effectiveness for imaging and deterministic QD device integration is of high technological relevance, since high quality imaging at the single-photon level is difficult to achieve, with only a single demonstration having been performed to date, with a high-end, LN2-cooled camera. The candidate demonstrated the effectiveness of the technique by fabricating circular Bragg grating cavities containing single positioned QDs.

While a lot of the device work was directly based upon prior techniques developed by other groups, the QD material system is very interesting because of the ability to reach C-band telecom wavelengths, and the ability to perform wide-field deterministic positioning demonstrated here certainly makes the platform very promising as a whole. In addition, the pulsed two-photon interference measurements, to my knowledge the first reported for this class of QDs, and in cavity-coupled photons, help demonstrate the reasonable promise of the platform, and indicates the next challenges, in particular when compared to competing material systems.

Overall, I find contributions of this article to be of high technological relevance.

The candidate's contributions to this paper were:

- Optimization of QD growth of epi-stack for processing
- µPL imaging, devising the data analysis approach to localize single QDs
- Writing scripts to analyze µPL maps and determine absolute positions of QDs
- Fabrication:
    - Creation of eletron-beam lithography masks with cavities aligned to single, positioned QDs
    - Etching of the cavities
- Optical characterization of cavities in µPL
    - Identification and study of exciton complexes in temperature-, power-dependent, and polarization-resolved µPL, correlation spectroscopy (non-resonant excitation), determination of photon extraction efficiency for the QDs in cavities
- Data analysis and interpretation

- Preparation of the manuscript. The candidate was a corresponding author.

The Article has not yet been published, and is currently available as pre-print. I have a number of comments and suggestions to improve the quality of the article:

Comment # 15 (major): Wide-field imaging of telecom O-band QDs for deterministic fabrication was demonstrated in the past by Hu et al. , Photon. Res. 10 B1 (2022) . I think this work should be cited and differentiated from what was done here. My understanding is that in that publication a LN2 cooled InGaAs camera was used, which provides a somewhat lower noise background. Also, is the candidate attempted to perform imaging in samples that did not feature the back metallic mirror, it would be helpful for others to read about it. More generally, it would be extremely helpful if the candidate could expand on what the achievable SNR is as a function of extraction efficiency, given typical detector noise values.

Comment #16 (minor): Are the low coherence times are due to spectral diffusion or pure dephasing? Also, is there any evidence that fabrication or growth have major contributions to the low coherence times? Even though coherence times are not so good, they are more or less comparable with those of other telecom QDs in fabricated nanostructures.

Comment # 17 (major): Regarding the lower purity and coherence times at higher powers, is the presence of other nearby QDs involved? While the devices feature single QDs emitting at a narrow filter window, there is still a relatively high density of QDs surrounding the positioned ones, with emission elsewhere, so it's not unreasonable to think that quasi-resonant excitation could be accessing such QDs.

Comment # 18 (major): Have LA-photon or direct resonant excitation of the QD? It would be interesting to see if the coherence time can be significantly improved, since these two excitation methods are minimally detrimental to the single-photon coherence times.

Comment # 19 (major): What is limiting the post-selected visibilities for the different excitation powers, or why is there such large variability? Close to zero delay, well below the coherence time, it should be always very high, unless there's a significant spatio-temporal and polarization mismatch between the two photons being interfered. I think polarization and spatial mismatch can be well controlled in the experiment, though polarization control can be tricky when using optical fibers. Is temporal mismatch, e.g. due to jitter cause by quasi-resonant excitation, an issue?

Comment # 20 (major): What QDs were selected as references for the radiative rate enhancement estimates? This is not very clear. E.g., were the 8 reference QDs located inside cavities, but spectrally detuned? Or were they completely outside any cavities? This is not very clear in the text, though it's somewhat important because there's a chance for radiative rate suppression of QDs located at resonance nodes in the cavity.