Dear Editor,

**RE: JoVE50216 ‘Fabrication and Characterisation of both Photonic Crystal Slow Light Waveguides and Cavities’**

First we would like to thank you for the opportunity to publish our work within the journal of visualized experiments. We would also like to thank the referees for taking the time to read our submission, we agree with the referees’ comments and where we feel appropriate have amended our paper to make their and our points clearer. Our answers to the referees and our corrections can be seen below and within the re-submitted manuscript.

Yours sincerely,

Christopher Reardon, Isabella Rey, Karl Welna, Liam O’Faolain and Thomas Krauss

**Reviewer #1:**

*Minor Concerns:*

We thank the reviewer for their comments and agree with their suggestion of dropping “both” from our paper’s title. The title now reads: “Fabrication and Characterisation of Photonic Crystal Slow Light Waveguides and Cavities”.

We appreciate the reviewers remark as to our fabrication techniques being applicable not only to silicon but to other semiconductors, as such we have included the following: “*Although the protocol outlined in this paper is optimised for SOI, the general principle behind the fabrication methods are also valid for the fabrication of devices into other semiconductors: of course, when changing from silicon, careful consideration of etch-tool, etch-chemistries and mask materials would need to be made.*” within the "Sample fabrication" discussion section of the paper.

We thank the referee for his suggestion to add more background information on slow light and resonant cavities. A new paragraph now appears at the beginning of the discussion section on slow light, where we have also added a new Reference [34]: *“The significance of the group index as the key parameter to measure slow light originates from the dispersion diagram or band structure ω(k) typically used to describe the dispersion of a photonic crystal waveguide.34 The local slope of the dispersion curve ∂ω/∂k corresponds to the group velocity vg, i.e. the speed at which the electromagnetic energy travels through the waveguide, which can be equivalently described by the group index ng=c/vg. Values of ng around 5 correspond to the fast light regime, whereas higher values are typically considered to fall within in the slow light regime.”* As for resonant cavities we have added the following: *“Photonic crystal cavities confine light in-plane in two dimensions, in contrast to photonic crystal waveguides, where light is guided in one dimension. This allows the storage of light within ultra-small volumes, which is described by an energy decay, analogue to i.e. that of an electronic resonator. In photonic systems, this decay is associated with the photon lifetime of the cavity and is of exponential form, hence resulting in a Lorentzian lineshape of the peak. The ratio of the peak centre wavelength to the Full-Width Half-Maximum represents the Q-factor.”* However, we do not feel that introducing illustrations of the mode profiles would aid our audience to better understand the measurement techniques described here, which focus on characterisation of wavelength spectra.

**Reviewer #2:**

*Minor Concerns:*

We thank the reviewer for his kind remarks and agree that ‘set-up the exposure as per the system’s user-manual’ could be confusing. We felt that including a detailed protocol focussed on the set-up of our EBL system (i.e. loading, measuring the sample, focussing the electron-beam, setting dose requirements and calculating dwell times, etc.) would be counter-productive as potentially the reader’s system could be very different. However, hopefully the following sentence, now included in the paper, makes our point clearer: *“Set-up the exposure as indicated in the user-manual of your specific electron beam lithography system.”*

We agree with the reviewer that our cleaning protocol may well be specific to our exact system. As such, we have now included the following details as to our RIE system: *“This procedure is optimised for our system which consists of a parallel-plate, cathode loaded RIE, with a main chamber 12 inches in diameter by 14 inches in height, including a 12 inch port with both throttling valve and turbo-molecular pump attached.”*

The resulting etch rate of silicon using our specific RIE and parameters is 150 nm/min – we have now included the following statement into the paper to highlight this fact: *“…*etch the sample for approximately 2min (the etch rate of silicon for these etch parameters is approximately 150nm/min), while ensuring that a…*”* The etch rate between waveguide trenches and photonic crystal holes is different. Trenches etch faster than holes mainly due to the relative ease at which volatile silicon species, from the trench, can be removed by the pumping system of the RIE. Our protocol is optimised for the most critical part of our device, namely the photonic crystal. If the etching of waveguides alone was required, a new protocol (based upon the one outlined in this paper) may require optimisation.

We agree with the reviewer about our protocol sub-section 3.3 which does not make it clear that this procedure’s purpose is the removal of any remaining ZEP. To avoid further confusion we have altered the sub-section to now read: *“Sample Cleaning to remove remaining electron sensitive resist – after dry…”*

In answer to the reviewer’s point about our discussion section. The mis-alignment due to thermal instabilities within the e-beam lithography system can be as high as 100 nm/min in absolute terms. While this is quite a substantial error which would result in large losses within any photonic crystal device, a number of other points must be taken into account: namely, the beam drift is not entirely random, in that the position error of one hole is related to the position of the following and preceding hole. For example, if one hole is out of position by 5 nm the next hole will be out of position by either 4 or 6nm (assuming a 1 nm per hole drift), thus considerably reducing the hole-to-hole error and consequently the attributed loss. Secondly, the speed at which the machine writes each hole also has an effect, as it is the ratio between the rate at which holes are exposed and the beam drift that determines the hole misplacement, i.e. for the same beam drift (thermal instability), a faster beam speed reduces the positioning errors. To make this point clearer, within the sample fabrication discussion we have added/amended the following: *“…chamber (even at only a few nanometres per photonic crystal hole) results in significant stitching and possibly pattern distortion errors with respect to photonic crystal tolerances. This error is random in nature, from one exposure to another, but can be as high as 100 nm/min (absolute positional error). The relative positional error (i.e. between one photonic crystal hole to another) can be on the order of nanometres, which can be further reduced by increasing the speed at which the pattern is written. These issues can be further negated (although never completely removed) by allowing the system to settle after first loading the sample.”*

The use of Ar/H2 plasma and O2 plasma is due to their different etching properties. Ar/H2 are used due to their ion-bombardment capabilites and are able through ion milling to clean the RIE chamber of most general contaminants (i.e. metal residue, silicon residue, etc.). O2 plasma is used instead in an ashing capacity, to remove any remaining polymers or organics from the chamber. To highlight these two points the sample fabrication discussion has been amended to read: *“…Ar/H2 plasma etch (used to remove metal and silicon contaminants through ion bombardment) followed by O2 plasma etch (used for the removal of polymer and organic residue through plasma ashing) described…”*

**Reviewer #3:**

*Major Concerns:*

We thank the reviewer for their remarks and would like to answer them. The functional wavelength range of our proposed photonic crystals is centred at 1550nm as we, as a research group, have focussed on the wavelengths of interest to the telecoms industry. We now regularly fabricate photonic crystals that target the 2.7–3.5µm range which, however, require different substrates i.e. an SOI wafer with both a thicker silicon top-layer and buried oxide layer; thus the fabrication protocols have had to be re-optimised for this wavelength range. To avoid any confusion, within the paper we have added the following paragraph to the discussion section: *“The fabrication protocol of this paper is optimised for devices targeted at an operating centre wavelength of 1550nm, however devices have also been prepared for the MidIR (2.7-3.5µm) regime using fabrication protocols based on the ones presented here.”*

As to the reviewers second point, we understand his concern but to date have not experienced any issues with our laser sources due to environmental conditions. Each of the sources used within the protocols of this paper, are commercial systems and while it is true that the tunable laser experiences some fluctuations immediately after start-up, it is sufficient to let it stabilise as described in the unit's specifications manual. Note that for the case of measurement of the group index of waveguides, we employ a broadband Amplified Spontaneous Emission light source, and thus the recorded wavelength is determined by the Optical Spectrum Analyser instead.