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Large Scale Site-Controlled Fabrication of Single Photon Emitters in Silicon Nitride Nanopillars

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Abstract: A high yield (67%) method of creating single photon emitters in annealed silicon nitride on silicon oxide pillars is demonstrated. Furthermore, the SPE emitter placement precision is found to be between ±30nm- ±85nm.

1. Introduction

One of the key difficulties facing practical large scale quantum optics is the difficulty of integrating single photon sources with integrated quantum photonic circuitry. Integration of single photon sources with quantum photonic circuitry arises from two main issues: placement issues and materials issues. The material difficulties arise from the need for hybrid integration of different material platforms where the single photon source and photonic circuitry are made from different materials [1][2]. Alternatively, if a material has native emitters it may be difficult to fabricate high quality photonic circuitry out of it scalably[2]. The second major issue is the lack of lithographically defined site-controlled emitters, in many platforms emitters are formed at random making large scale integration of emitters difficult, either requiring extensive SPE prelocalization methods or painful placement of nanostructures containing SPEs. Recently, bright and stable native single photon emitters were discovered in Silicon Nitride (SiN)[3]. The discovery of such native emitters promises simple monolithic integration into industry standard and scalable SiN photonic circuitry while avoiding the pitfalls of hybrid integration such as fabrication complexity and poor light coupling [1][2][3][4]. In this work we addressed the second major issue of fabricating these emitters lithographically through the development of a large-scale high-yield fabrication process for these emitters with deeply sub-diffraction limited placement precision.

2. Results

The process of creating site controlled single photon emitters consists of growing 50nm of SiN via High density plasma enhanced chemical vapor deposition (HDPCVD) onto SiO_2 coated Si wafers. The SiO2 layer is approximately 3um thick. Once the full thin film layer stack has been fabricated the nanopillars are created. To create nanopillars, first the pillar is defined lithographically using ebeam lithography. This is followed by the deposition of a chrome hardmask and liftoff. At this point the pillar is etched using ICP plasma etching. Importantly, the etch is allowed to overshoot the SiN layer and cut into the SiO_2 layer. The result are pillars that are 90nm tall with a 40nm SiO_2 base and a cap of 50nm of SiN. The diameter of the measured pillars is 170nm. A cross section of the fabricated pillars can be seen in Figure 1b. This was done to avoid any SiN between layers and the possible formation of emitters between pillars. Finally, after the etch, the chrome mask is removed using chrome etch. Critically, the pillars are then annealed using a Jetfirst rapid thermal annealing system (1100C). An SEM of the resulting pillars can be seen in figure 1c.

Once the pillars have been fabricated we explored two major questions: the yield, and the placement accuracy. To assess the yield of single photon emitters per pillar we used a home built confocal photoluminescence system which is also capable of performing the Hanbury-Brown-Twiss autocorrelation measurements. Spatial imaging of the pillar array demonstrates that the vast majority of the pillars exhibit photoluminescence as can be seen in Figure 1a. Once the spatial map has been taken we measured the autocorrelation curves of 55 pillars sequentially to avoid any sampling bias. This includes pillars that do not appear to be promising. An example of a good measured autocorrelation curve can be seen in the inset of Figure 1d. Finally, after the autocorrelation curves have been measured they were fitted with a standard 3 level model to extract the $g^{(2)}(0)$ value. From the 55 emitters we measured we found that 67% have $g^{(2)}(0)$ values below 0.5 indicating that 67% of the measured pillars contain single photon emitters. Furthermore, the vast majority of the measured pillars exhibit some level of antibunching indicating the presence of multiple emitters or dim single photon emitters with poor signal to background noise levels. These results when taken together confirm that this process is capable of producing single photon emitters deterministically since the yield does not follow a typical stochastic poissonian distribution. To assess the placement accuracy lines of emitters are imaged in the photoluminescence maps. The emitters are then fitted with gaussian curves to find their centers. By looking at the variation in the measured emitter center we find that the emitters have a maximum variation of approximately ±30nm. Due to symmetry of the pillars this indicates that the emitters are occurring near the center of the pillars and with high precision.

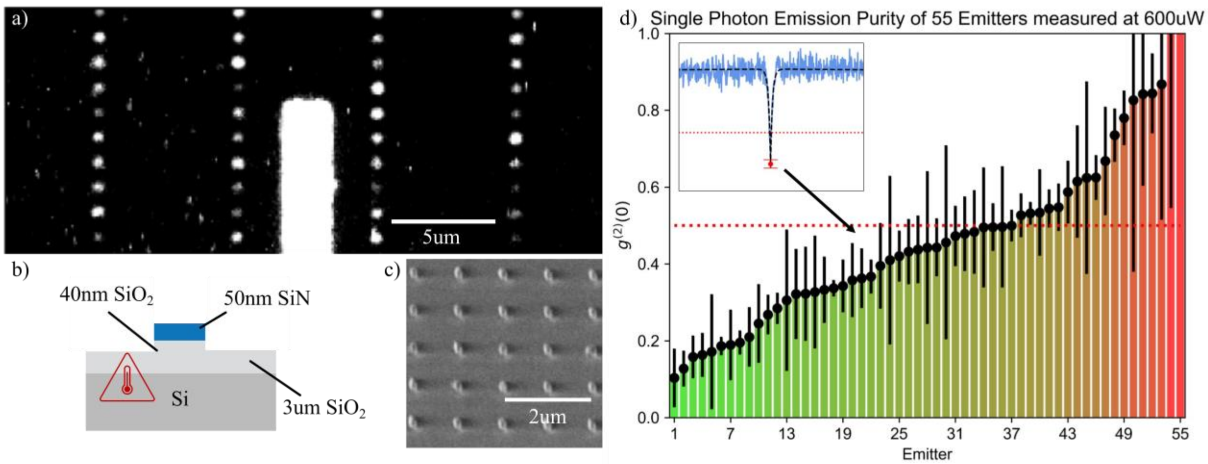

Figure 1. (a) A scanning photoluminescence map taken with an excitation wavelength of 532nm, the cross is an alignment marker, and the pillars are clearly visible in the PL map (b) A cross section of the fabricated pillars (c) A scanning electron microscope(SEM) image of the nanopillar array. (d) A summary of the $g^{(2)}(0)$ values retrieved from 55 different pillars. The error bars shows the fit uncertainty. The inset shows a autocorrelation curve and how the $g^{(2)}(0)$ is retrieved from fitting with a 3 level model.

3. Conclusion

This method of single photon emitter fabrication is capable of producing industrial quantities of single photon emitters with yields of at least 67%. Furthermore, this method allows for the lithographic definition of these emitters with relatively high spatial accuracy (±30nm to ±85nm). Finally, the emitters being patterned are native to silicon nitride avoiding many of the issues associated with hybrid integration. These three features promise to pave the way towards quantum photonic systems deterministically and seamlessly integrated with large numbers of single photon emitters.

References

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