Cascaded Field Enhancement in Plasmonic Nanostructures

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Abstract

Composite plasmonic nanostructures designed to enhance electromagnetic fields in a cascaded manner have been fabricated using electron beam lithography. The structures consist of three stacked metallic nanodiscs separated by dielectric spacers. We have optimized the fabrication process and performed initial characterization of the structures. Cascaded enhancement of electromagnetic fields in these nanostructures will be used for single molecule Raman studies.

1. Introduction

It is well-known that metallic nanostructures can produce strongly enhanced electromagnetic fields when excited by light. Such enhanced fields have potential for applications in biomedicine, chemistry, sensing, optics and data storage[1]. While early applications such as SERS used enhancements occurring randomly on roughened metal surfaces, many applications require reproducible field enhancement localised at known positions on the sample surface. In addition to localisation, very strong field enhancements are necessary for many applications such as for studying single molecules. An approach for generating very strong enhancements by cascaded field enhancement was proposed by Li, Stockman, and Bergman[2], where multiple self-similar plasmonic resonators of decreasing size are fabricated, each smaller one lying in the enhanced field of the larger. Experimental attempts to fabricate such structures in the initially proposed configuration failed to show cascaded enhancement[3, 5]. Kravets *et al.*[4, 5] replaced the planar chain of nanospheres with an out of plane stack of gold disks separated by dielectric spacers. These structures were the first to successfully demonstrate the cascaded enhancement effect, with enhanced fluorescence from double structures[4] and Raman scattering from triples[5]. It is upon this foundation that this work builds.

2. Fabrication method

The electron-beam lithography steps used by Kravets *et al.* to fabricate double structures is shown in Fig. 1. A column of over-exposed PMMA is formed in the centre of an annular region where the PMMA is exposed in the normal fashion. This allows the PMMA to be used as both a positive and negative resist in one lithography step. This method is advantageous in that it allows double structures to be made in a single lithography step, and triples in two. However, double structures made with this method were seen to have fairly poor reproducibility when studied in SEM (Fig. 3). Additionally, with repeated use the samples are expected to degrade as the overexposed PMMA will still be slightly soluble in common solvents such as acetone. This suggests that overexposed PMMA is not the most suitable material for the dielectric column. The fabrication method was therefore modified to replace the over-exposed PMMA with a column of electron-beam deposited silicon dioxide. A summary of the fabrication method can be seen in Fig. 2, and a typical area of the sample surface using this refined technique is shown in Fig. 3. Clearly the sample reproducibility has improved significantly, making it much more suitable for applications. In contrast to the over-exposed PMMA, SiO_2 is insoluble in most common solvents and should withstand repeated use much more robustly.

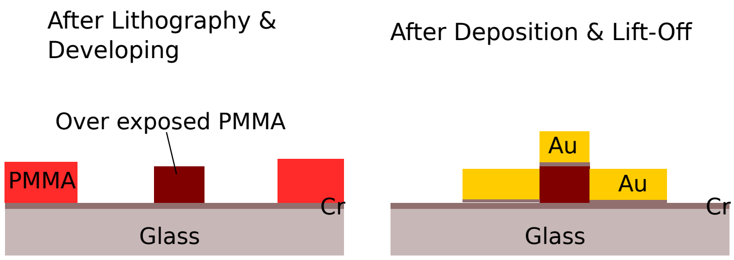

Fig. 1: The previous procedure for fabrication of double structures.

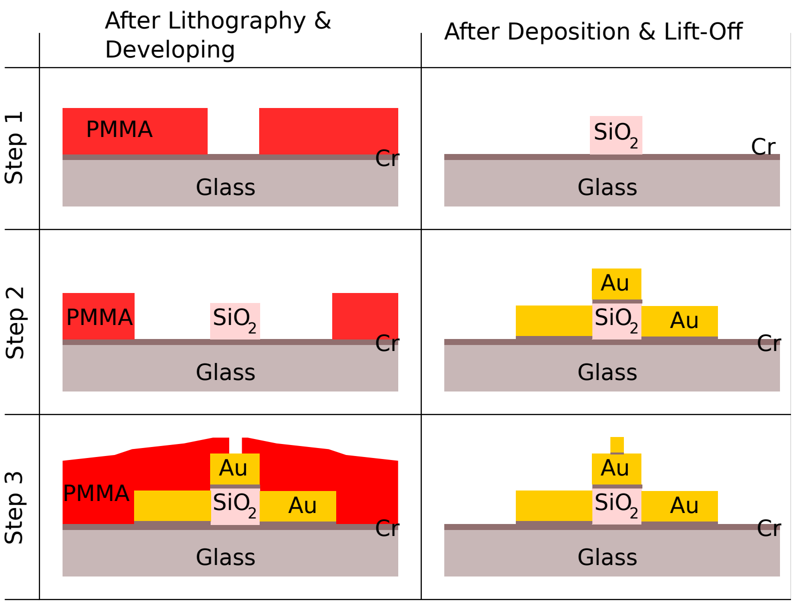

Fig. 2: The improved procedure for sample fabrication. Also shown is the addition of the third dot.

2. Results

Triple structures fabricated with the improved method can be seen in Fig. 4. While reproducibility of the third dots is still in need of improvement, the method now allows very reliable reproduction of the two larger disks. Large areas of the sample exist where all three layers of the structures are intact in almost every case, a significant advancement in reproducibility when compared to the previous approach. Lessons learnt from this sample should also allow the third dots to be fabricated more reliably on future samples.

4. Conclusion

A more reliable approach to the fabrication of composite plasmonic nanostructures for cascaded enhancement of electromagnetic fields has been developed. While the fabrication process is slightly more

ISBN 978-952-67611-2-1

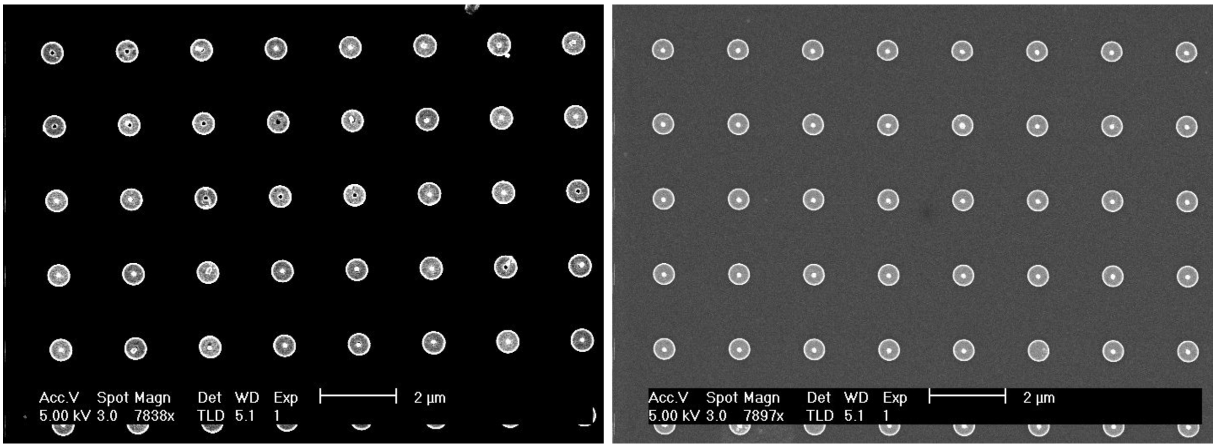

Fig. 3: Improvements made to the reproducibility of the method. Left: SEM image of a sample made by the old approach. Right: SEM image of a sample made with the new method.

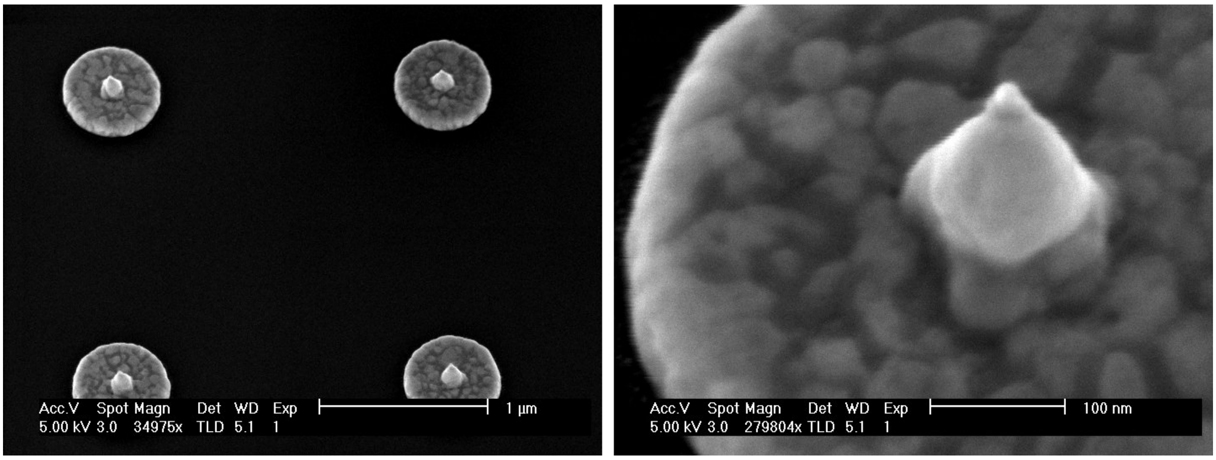

Fig. 4: SEM image of newly fabricated triple structures using the improved method.

complex than that previously used, the significant improvements in reproducibility of the structures and likely improvements in the robustness of the samples under repeated use justify this approach. Future work will seek to further improve reproducibility of the third dots, and consider different sample geometries and chemical and biological applications in different ambient media.

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