Novel, Successful Coating for Ln doped UCNPs in Biomedical Applications and Experimental Verification of Field Enhancement based on Surface Texturing

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Abstract*-Upconverting nanoparticles (UCNPs) have been of crucial significance in multiple applications involving photochemical, biomedical and optical ones. For the biomedical applications, one main problem that always stands as a challenge, hindering the upconversion scheme from being deployed inside human cells, is the challenging trade-offs among biomedical and field enhancement requirements imposed by the biomedical design constraints that deprive the UCNPs from field enhancement. Another challenge is imposed due to the constraint on the material choice that should achieve the required targeting, treatment/imaging, and electromagnetic design objective without any harm threatening the human body, which involves the dose limited by biodegradability and biocompatibility of the material. Although multiple field enhancement and manipulation techniques have been applied to UCNPs, there has never been a generic, material independent field enhancement method that could be invoked in biomedical applications without harming the human body despite achieving the required dose. This is a global transformation in the field of photoluminescence (PL) enhancement where there are constraints in the material, especially in biomedical applications, which has been the focus of this work. A novel, broadband, material-independent field enhancement mechanism is verified in lanthanide doped UCNPs through a novel, successful coating method that overcomes another worldwide challenge of surface texturing without lithography.

Keywords: **photoluminescence, upconverting nanoparticles, field enhancement, surface texturing, experimental**

I. INTRODUCTION:

Based on the literature review done before [1], the only two feasible approaches for field enhancement are the material based and the surface texturing ones. While the material dependent one is exhausted in a prior work [1], this approach is still problematic in multiple applications where the several constraints on the material make it inapplicable. Thus, this leads us to think of another material independent approach. Surface texturing is one approach that could resolve this problem through increasing the anti-reflectivity and thus increasing the incident intensity to the core layer and has been introduced in the prior work referred to. This is crucial for the direct correlation between the output PL and the incident excitation intensity shown in all literature studies focusing on lanthanide doped UCNPs. Numerically, a solution for this problem has been worked out and explained in a prior work [2]. However, one main problem remains which is the way it could be implemented to UCNPs. The problem of practically implementing the moth-eye structure on upconverting nanoparticles without lithography seems an unsolvable challenge that we had to go through in this work. Conventionally, it's known worldwide that such a surface texturing way could be only implemented to the solid core layer and that there is no way in any means to implement it to the loose coating, which is the property of any bulky biodegradable material at the macroscale. The other main challenge is the application of successful coating to this specific UCNPs chemically for the coating to remain stable, meeting all the biomedical and electromagnetic design objectives explained before in a prior work[3]. Had we only depended on the physical attachment of the coating to the core layer, this will never ensure its stability and it might disintegrate in a short lifetime causing biocompatibility problems. Here, we utilized both physical and chemical attachment of the coating layer to the core UCNPs through a novel coating process considering the specific materials of concern. Moreover, the broadband field enhancement technique has been implemented to multiple coatings and verified practically, for the first time. Then, the challenge of the large UCNPs size referred to earlier in a prior work [1] has been resolved during the coating process.

II. MATERIALS AND METHODS

A) Numerical Studies: The numerical studies were done in a prior work[2].

B) Synthesis and Characterization of Coated UCNPs:

As for the choice of the coating, all possible targets published any time till September 2020 for SARS-COV-2 proteins were reviewed. Then, molecular docking was conducted on 70 materials of the best of them, as attached in the supplementary material. Multiple concentrations of the ligand/host were implemented in the form of thin film. The optimum concentration film was then used as a coating for the core layer of the nanoparticles.

Because of the core layer represents the first design objective as explained in a prior work [3], we needed to measure the zeta potential to know the extent of strength of the coulomb forces and choose a coating that can strongly bind to the core layer physically. Then, we worked out an unprecedented coating method to ensure the chemical binding of the core to the coating layer and verified it using Transmission Electron Microscopy (TEM) of the uncoated versus the coated sample. A further verification was explored through the FTIR of the coated versus the uncoated sample.

To verify our hypotheses that this coating was not only successful and meeting all stability requirements, we measured the NIR-UV spectroscopic absorption of the sample to make sure that the local maximum at 976 nm of the uncoated sample[4] was still there. Furthermore, and more importantly, the photoluminescence (PL) of the uncoated sample was contrasted with that of the coated one to verify the field enhancement technique.

The chemical synthesis was done through the following procedure. UCNPs were synthesized as explained in another work.

They were then dispersed in cyclohexane. Then, 1g of 0.02 M UCNPs solution, 18 mL cyclohexane and 0.5 ml surfactant tween 80 were stirred for 10 min. Then, 1g of freshly prepared glucose derivative solution (1 M) was added to and sonicated for 5 min till a transparent water-in-oil microemulsion formed. To achieve dehydration, crosslink and carbonization of glucose derivative on the UCNPS, the solution was autoclaved, and the temperature was slowly raised to 120 ◦C at a rate of 3 ◦C min−1 and maintained at 120 ◦C for 2 h. Upon cooling down to room temperature, the products were centrifuged out of the solution by adding acetone and maintaining it for 15 min at 9000 rpm for each further washing time.

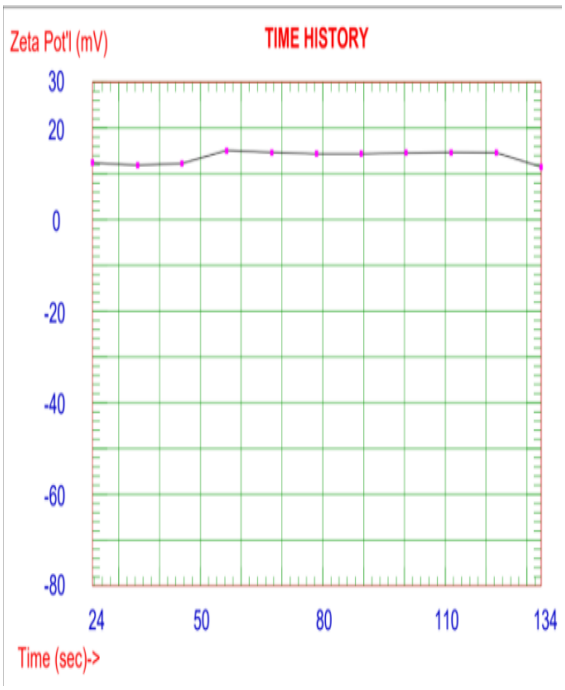
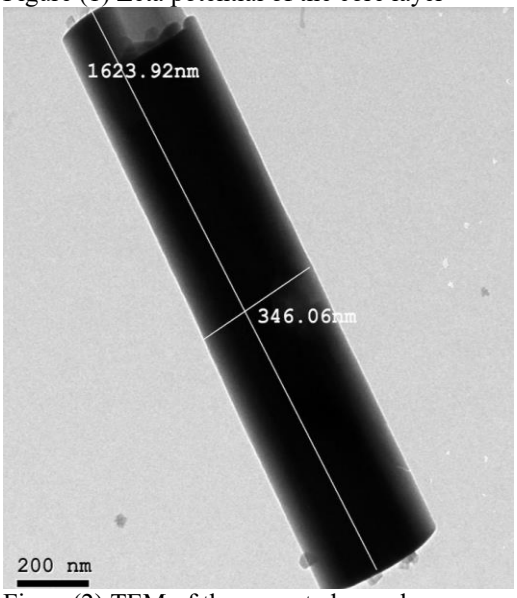
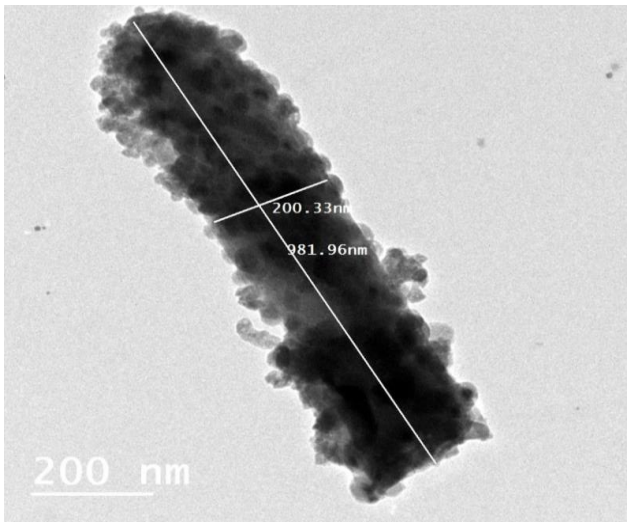


Figure (1) Zeta potential of the core layer

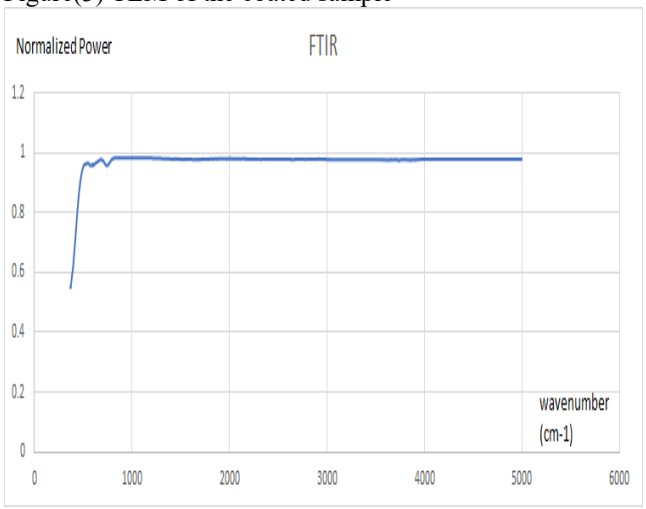


Figure(2) TEM of the uncoated sample

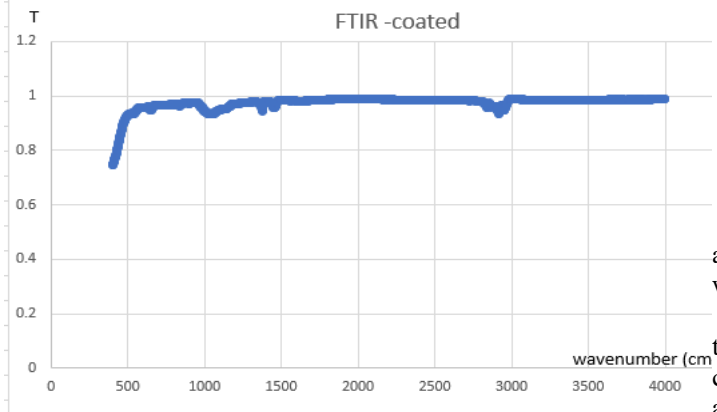
III. RESULTS



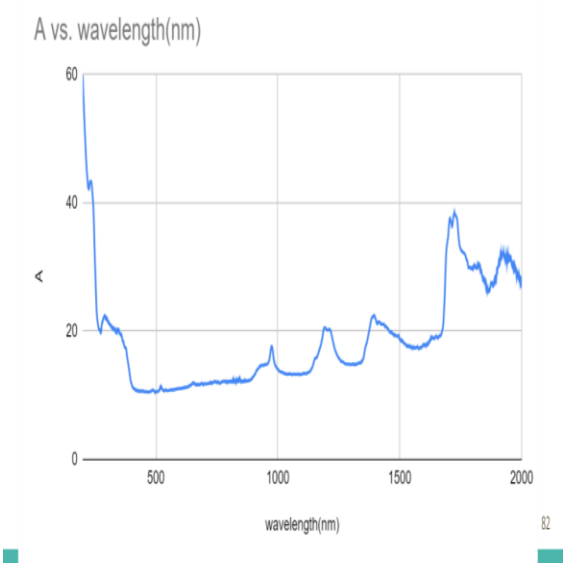
Figure(3) TEM of the coated sample



Figure(4) FTIR of the uncoated sample



Figure(5) FTIR of the coated sample



Figure(6) NIR to UV spectroscopy of the coated sample

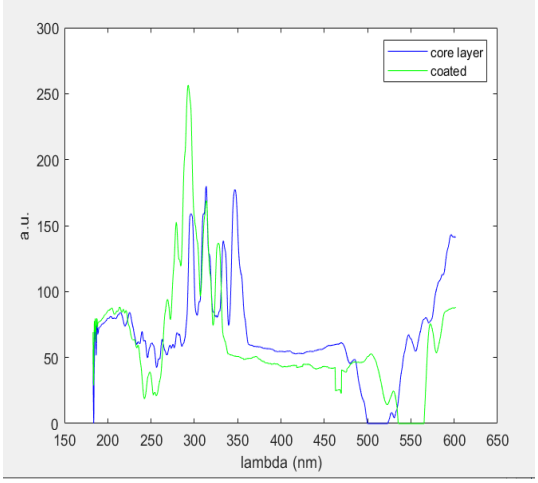


Figure (7) PL of the uncoated versus the coated sample at 0.7W excitation power and 980 nm

IV. DISCUSSION:

Since the zeta potential of the list of coatings has been already known from literature, it was only conducted in this work for the core layer only.

Figure (3), shows the effect of carbonization and coating of the uncoated sample shown in figure (2), which confirms the coating that is also confirmed by the FTIR results. It can be also noticed that the size problem has been resolved, which makes the size ideal for the cell uptake range and this overcomes the problem referred to in earlier work[4]. The surface texturing was, in a novel way, implemented to the coating, for the first time, despite its macroscale loose properties. However, we thought, unconventionally of its nanoscale properties and the more stiffness it develops at that

scale that differ from the macroscale case, which suggests the validity of applying it to the coating. The novel idea is that the intended chemical conditions allow breaking the long chain polymer used into smaller chains whose size depend on the temperature and separation distance depend on the concentration of the coating relative to the core layer in the overall precursor solution.

The FTIR of the coated sample, figure (5), shows that s=o bond and CH2 bond remained after coating, which means that the bonds required to attach to the virus are kept intact, which theoretically predicts the success of our coating procedure not to affect the biological function. However, the peaks shown in the FTIR of the coated sample as compared to the uncoated one -figures(4,5)- prove the chemical bond between the core layer and the coating layer, which further proves the validity of our hypothesized coating procedure.

Despite the absorption peaks that appeared apart from the 976 nm one, as compared to the uncoated sample shown in the same prior work, there is still a local maximum at 976 nm, which indicates that the excitation laser source used for the core layer can be also used for the coated sample. This is what we did to measure the Pl as shown in figure (7), that confirms the field enhancement in the UVC band and specifically at the 290 nm peak by 148%, using all biodegradable materials based on the biomedical application, which is a huge success and breaks a worldwide challenge that always hindered this technology from being utilized.

V. CONCLUSION:

In this work, the worldwide everlasting challenge of coating upconverting nanoparticles to resolve all the challenges of targeting inside or outside the human cells, improving stability and biocompatibility, not affecting the involved electromagnetic interactions through thickness optimization, using all biodegradable materials has been practically resolved and verified. A novel, material independent field enhancement technique has been practically verified, for the first time. More importantly, it has been implemented using a facile chemical method without any lithographic processes. The entire system has also optimized time and cost efficiency. Not only had the coating been successful to meet all these design objectives, but it even enhanced the field by 148% in the UVC band.

VI. ACKNOWLEDGMENTS

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VII. CONFLICT OF INTERESTS:

The authors declare no conflict of interests

VIII. AUTHORS' CONTRIBUTIONS

Dr. Usama and Dr. Ahmed did the molecular docking studies, and the rest of work was done by Noha.

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