

# Plasmonic Design for Optoelectronic Devices

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## Abstract

This work focuses on optimizing and enhancing the absorption of a MoTe<sub>2</sub> photodetector using plasmonic aluminum nanoparticles. Simulations were conducted using the finite-difference time-domain (FDTD) method to solve Maxwell's Equations. Optimization considerations involved both the thickness of the SiO<sub>2</sub> layer below the structure and the morphology and size of the Al structures. The resulting device proposed involves prolate Al hemispheres, which remain understudied in literature. The size-tuning allows for enhancement control in either the visible or near-infrared (NIR) region.

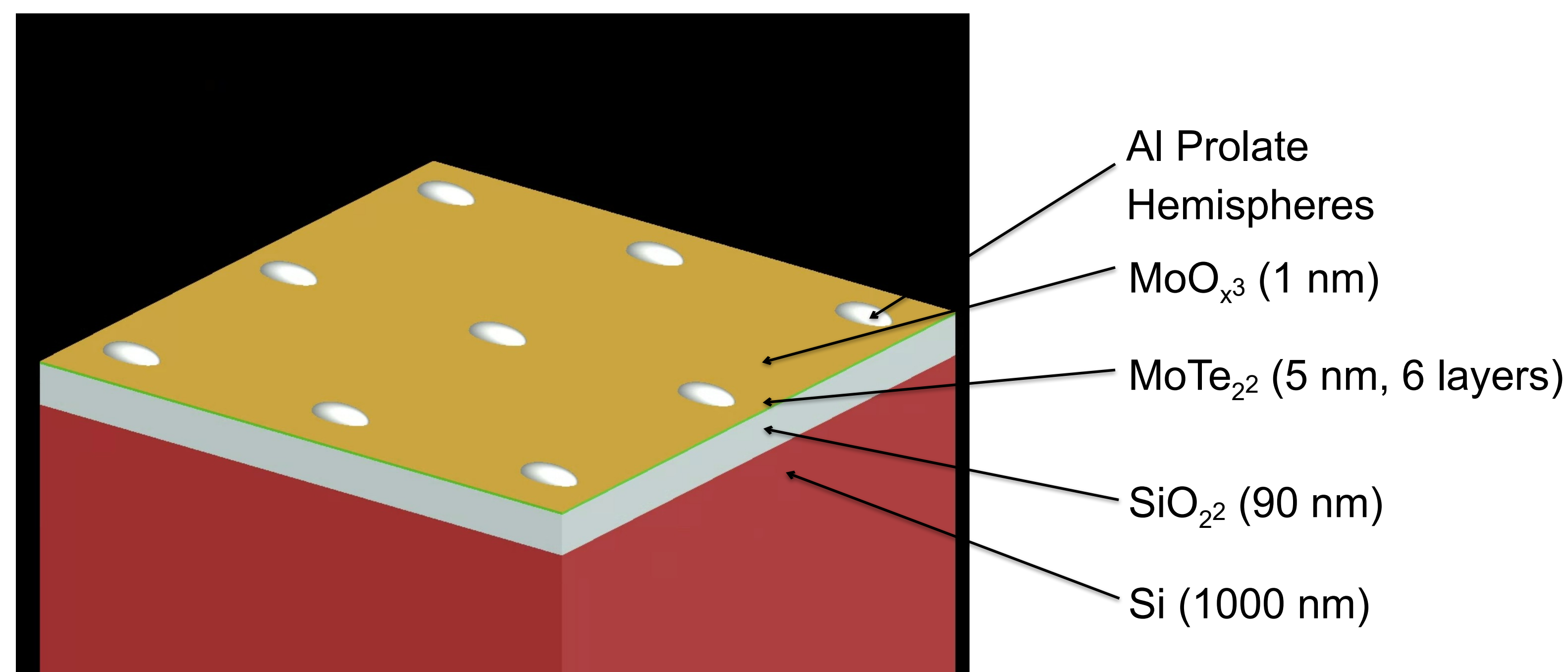


Figure 1: The device schematic used in this work.

## Introduction

Atomically thin 2D materials such as transition metal dichalcogenides (TMDs) have many desirable qualities (such as direct band gap at monolayer thickness) for optoelectronic devices. However, due to their thinness, less light is absorbed than in a bulk material. To counter this issue, plasmonic structures comprised of metallic nanoparticles can be employed.[1] These structures have size-tunable resonances that interact with electromagnetic radiation in and around the visible and NIR portions of the spectrum. These resonances enable enhancement of the electric field around the nanostructure, allowing for increased absorption in the TMD. An example localized surface plasmonic resonance (LSPR) spectrum is displayed in Figure 2, for one of the particles used in this study. Note the Fano resonance visible in the graph, with a dip visible before the peak.

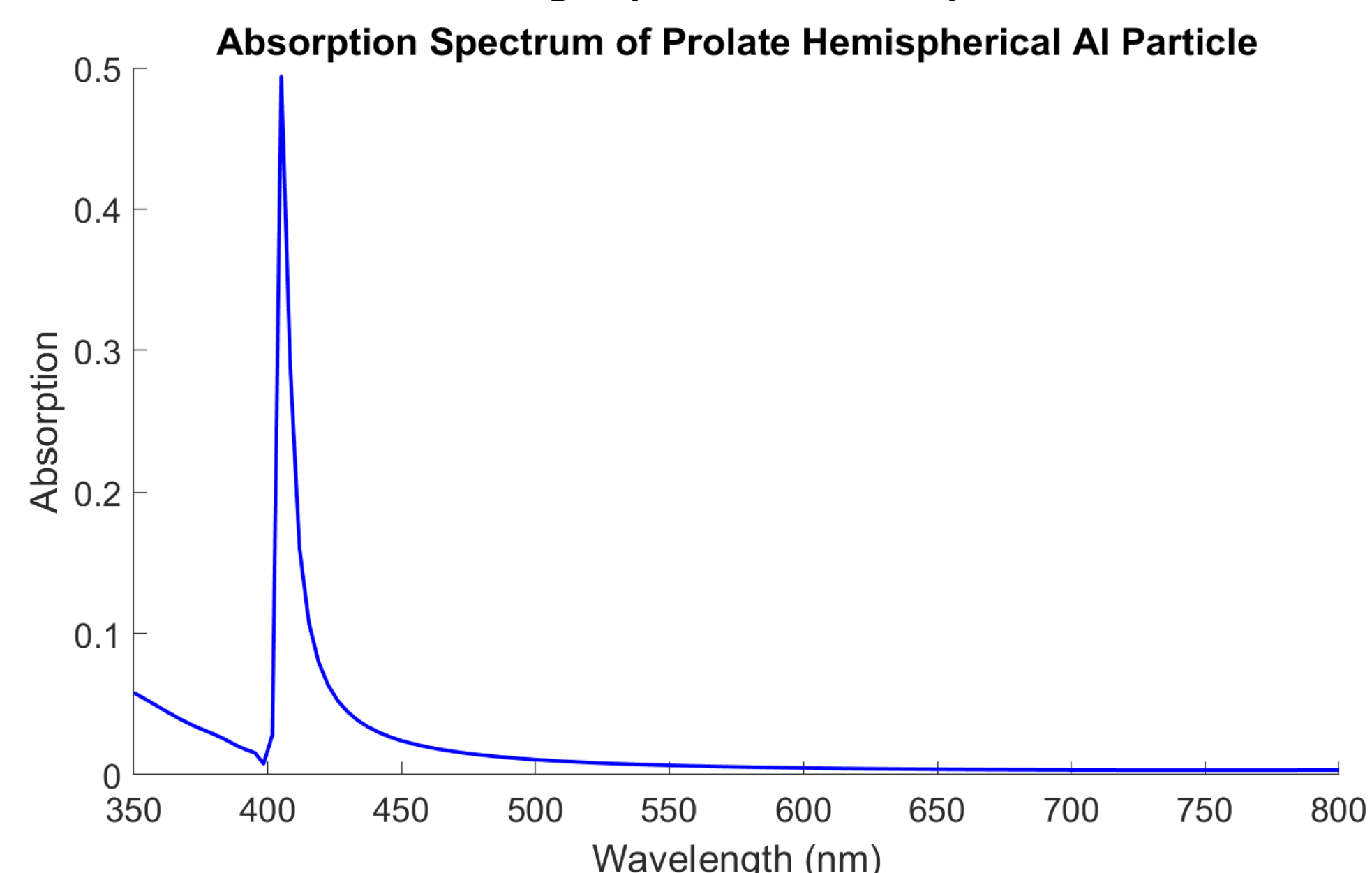
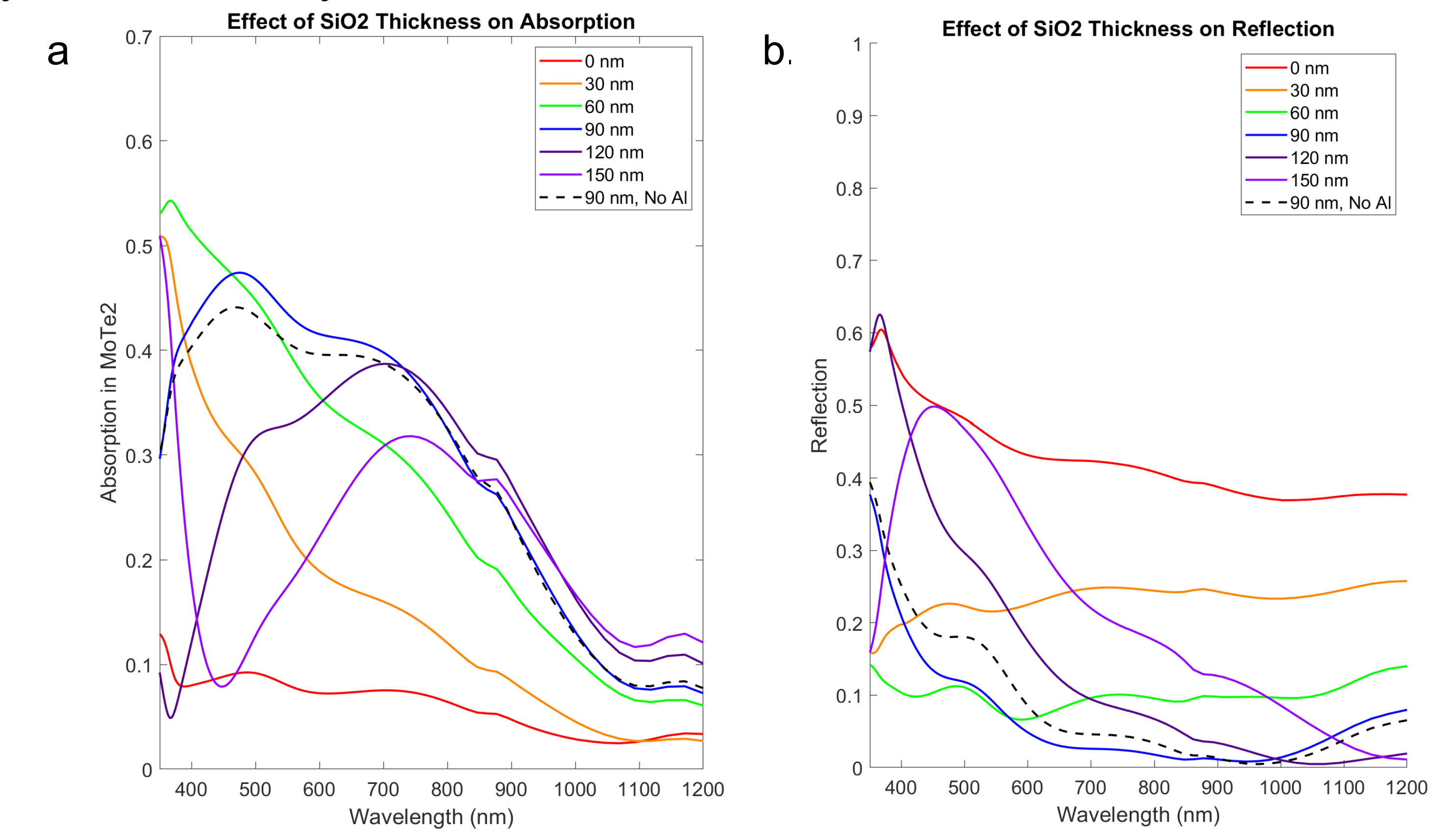


Figure 2: The absorption spectrum of a prolate aluminum hemisphere (104 x 52 x 52 nm), showing a strong localized surface plasmonic resonance.

## Optimization of the SiO<sub>2</sub> Layer

We found that interference effects associated with the thin film SiO<sub>2</sub> layer were ultimately beneficial to the device; however these effects had to be carefully tuned using the film thickness. The best performance occurred for a thickness of 90 nm.

Figure 3 (to the right): (a) The absorption in the MoTe<sub>2</sub> and (b) reflection from the device at different thicknesses of SiO<sub>2</sub>.



## Particle Morphology

We adjusted the particle morphology with the goal of using shapes with sharp edges so that the field would be enhanced specifically at these regions. We initially tested a nanodisk morphology, which did not show enhancement upon the optimization of the SiO<sub>2</sub> layer. We then tried using hemispheres which resulted in enhancement in either the blue region or the NIR region of the spectra, resulting in a tradeoff. Prolate hemispheres eliminated this tradeoff, resulting in enhancement in the region around 500 nm in wavelength without sacrificing absorption in the NIR region.

## Size Optimization

Various sizes of prolate hemisphere were tested (Figure 4(c)). The optimum particle size was found to be 104 x 52 x 52 nm (with the long axis parallel to the surface) for wavelengths near 500 nm. Alternatively, for NIR enhancement, dimensions of 192 x 96 x 96 nm were optimal. Device performances compared to the non-plasmonic control device are shown in Figure 5.

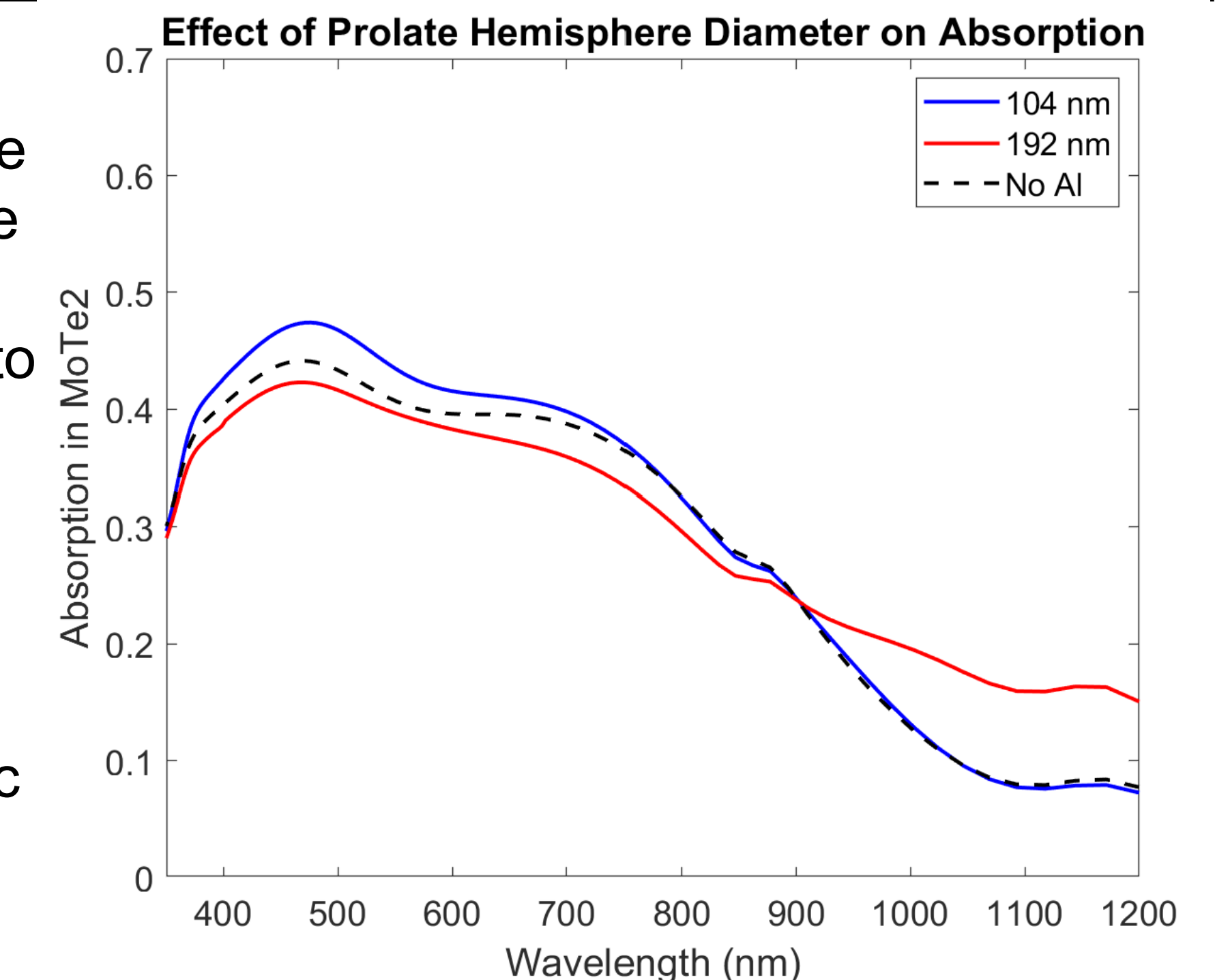


Figure 5: The absorption spectra of the optimized structures. 104 x 52 x 52 nm hemispheres, with enhancement around 500 nm (blue); 192 x 96 x 96 nm, with enhancement in the NIR region (red); non-plasmonic control (dashed black).

## Conclusions

This study focused on optimizing Al plasmonic nanoparticles for enhancing absorption in a 2D MoTe<sub>2</sub> photodetector. Both the SiO<sub>2</sub> layer thickness and the plasmonic structure morphology were optimized. Prolate hemispheres were found to be optimal plasmonic structures, enabling enhancement near 500 nm in wavelength or in the NIR region while sacrificing absorption in the 400-800 nm range. Thus, the design method also demonstrates enhancement tunability depending on desired application.

## Additional Questions?

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## References

[1] Wenjie Chen, Renrong Liang, Yu Liu, Shuqin Zhang, Weijun Cheng, Linyuan Zhao, and Jun Xu. Appl. Phys. Lett. 115, 142102 (2019).

## Acknowledgments

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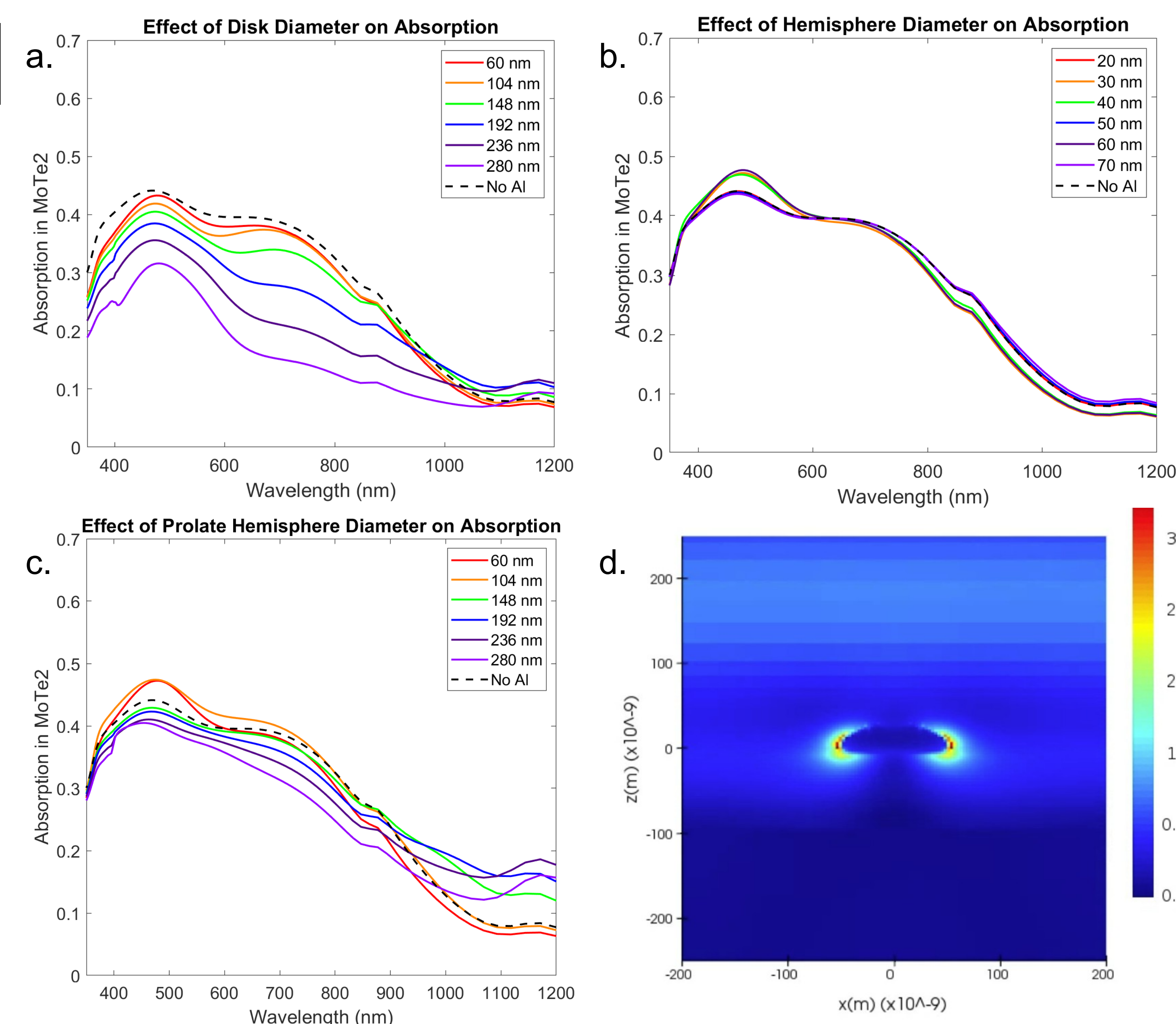


Figure 4: The absorption measured at different diameters for (a) disks, (b) hemispheres, and (c) prolate hemispheres of diameter ratio 2:1:1 (long axis is reported). (d) The enhanced spatial electric field intensity profile of a prolate hemisphere. The enhancement is larger near the sharp edges, as expected.