Optimization of 3D Layered Metal-Dielectric Stacks (MDSs) for Near-Field Fluorescence Imaging

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Introduction:

Nano-structures consisting of layered metal-dielectric stacks (MDSs) can be designed to have evanescent transmission and reflection coefficients that oscillate as a function of transverse wavevector and frequency [1]. However, these structures always suffer from the material losses and surface roughness that are detrimental to image reconstruction. As such, we propose an optimized planar anisotropic structure composed of alternating metal and dielectric layers as shown in Figure 1 and shows the fluorescence dipole imaging ability in the vicinity of the MDS surface.

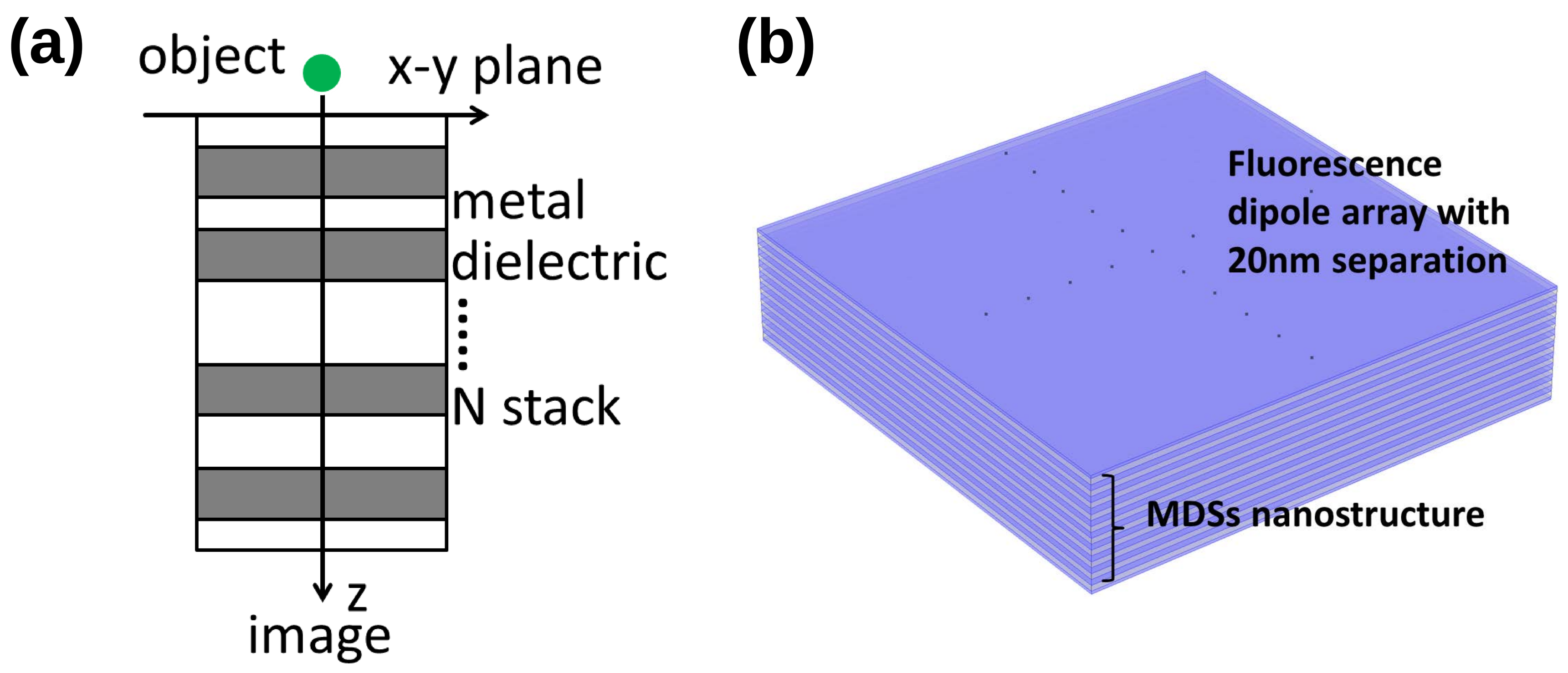

Figure 1. (a) Schematic diagram for the layered metal-dielectric stacks (b) COMSOL design geometry

Computational Methods:

Here we perform a full-wave three-dimensional electromagnetic simulation with Finite Element Analysis demonstrating the operation of the proposed technique by using COMSOL Multiphysics to solve the electric field transmitted through MDS. The transmission properties of the MDSs are first evaluated by using RF module and compare with transfer matrix calculations. In order to optimize the transmission and focusing capability, we manipulate the structure properties (such as number of stack layers and layer thicknesses) by performing parametric sweep.

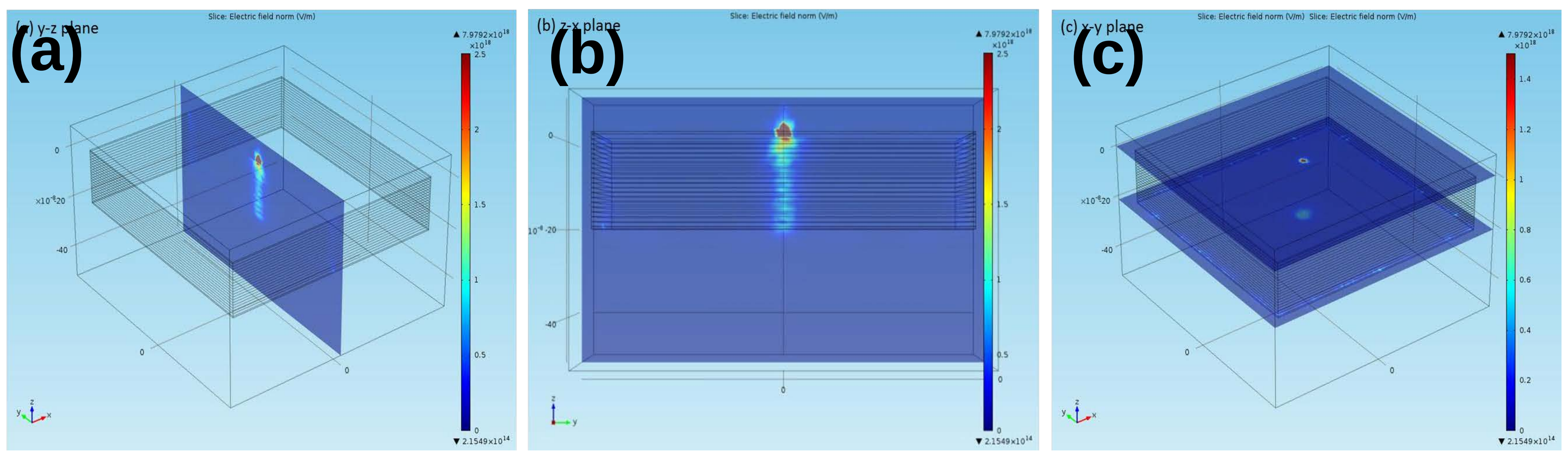

Figure 2. A finite element analysis shows the transmission property of MDSs in (a) y-z plane, (b) z-x plane, and (c) x-y plane

Results:

As shown in Figure 2, we find that for a dipole source emitting at visible wavelengths, imaging with a resolution beyond diffraction limit become possible on MDS structure that operates in an intermediate canalization regime [2]. This result is in good agreement with analytical results. In addition, we simulate dipole array on the same MDSs. As shown in Figure 3, the electric field distribution at the opposite side of the structure clearly shows the image of adjacent fluorescence dipoles can be resolved effectively beyond the diffraction limit.

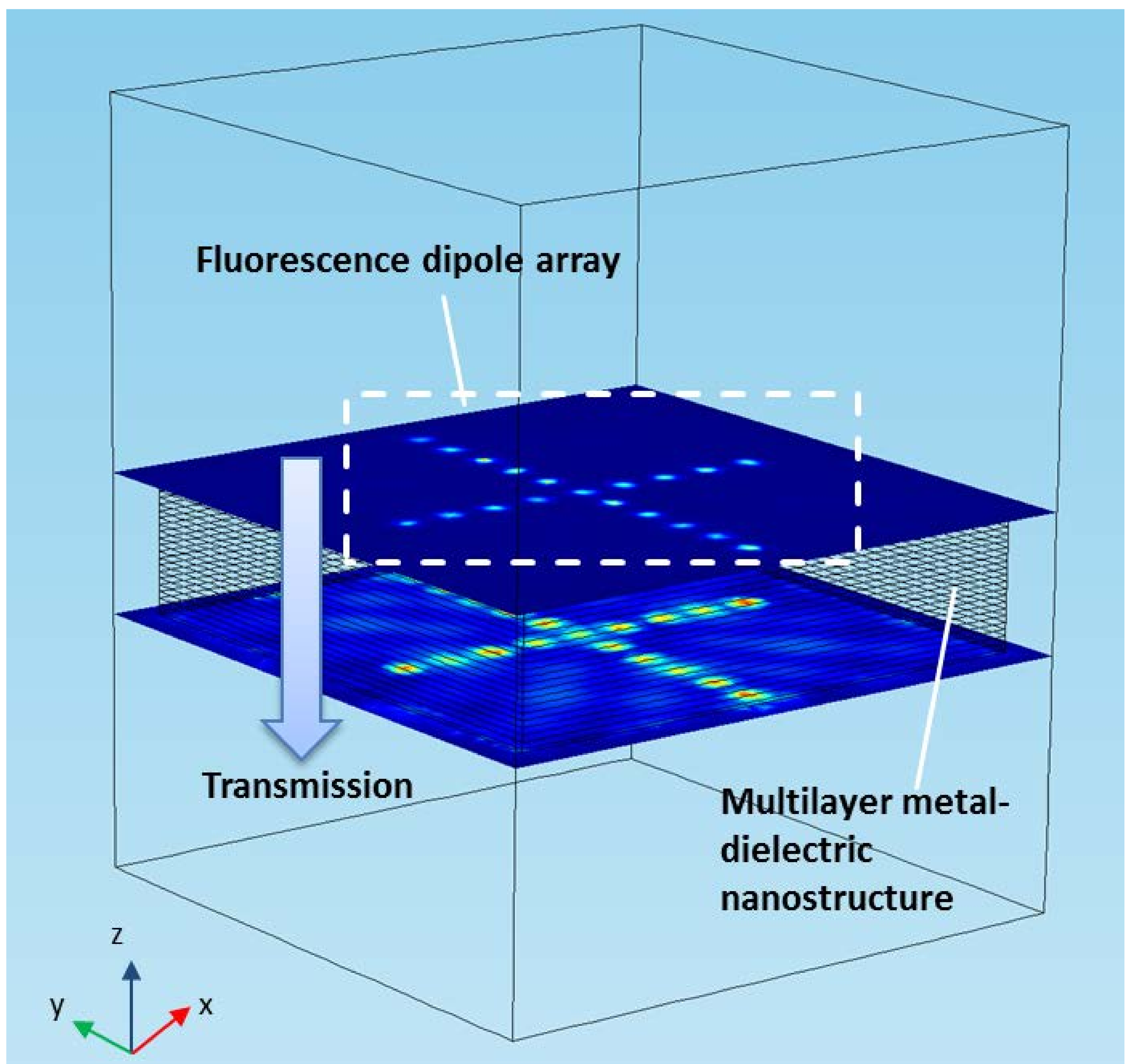

Figure 3. A finite element analysis shows the dipole array can be resolved on the proposed nanostructure

Conclusions:

We present simulations that suggest the feasibility of imaging a fluorescent source through MDSs. The realization and application of such nanostructure with the specified design is possible using current advanced nanofabrication techniques. When integrated with a sub-wavelength grating structure, microsphere or a fast near-field scanning probe, it could provide a means for fast fluorescent imaging with sub-diffraction limit resolution.

References:

1. Pendry, J. B. "Negative refraction makes a perfect lens." Physical Review Letters 85(18): 3966-3969, (2000).
2. Elsayad, K. and K. G. Heinze, "Multifrequency parallelized near-field optical imaging with anisotropic metal-dielectric stacks." Physical Review A 81(5), (2010).