Topologically Enhanced Guided Mode Resonance Sensing Of Fluid Refractive Index Variations

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Abstract

The present work explores the integration of guided mode resonance (GMR) structures and topological photonics, characterized by the presence of Jackiw-Rebbi (J-R) solution. The developed surface enhanced GMR structure may serve as a platform for refractive index sensing across various fluids, with the property of being more fabrication-friendly. GMR structures are engineered optical devices that leverage resonance phenomena to enhance light-matter interactions. By infusing the principles of topological photonics inspired by the J-R solution, we enhance the structure's optical resonances. These properties facilitate the creation of topological states, resulting in enhanced sensitivity to changes in refractive index. The interplay between GMR and topological photonics brings a novel approach for manipulating and enhancing light-matter interactions.

The proposed design is exposed to different fluids with distinct refractive indices, we exploit the structure's sensitivity to induce measurable spectral shifts in resonance frequencies. This paves the way for highly sensitive and versatile refractive index sensors capable of detecting minute changes in surrounding media.

We present a 3D model of a novel structure that incorporates a crosscut etched GMR as a key feature. We use COMSOL Multiphysics to simulate the structure using the electromagnetic wave, frequency domain (ewfd) physics under wave optics module. This allows us to model the high-frequency electromagnetic wave propagation at specific optical frequencies. Our structure shows potential for refractive index sensing in various fluids, which could enable new developments in sensing technologies and environmental monitoring.

We also show that our enhanced GMR structure has a significantly lower full width half maximum (FWHM) than conventional GMR structure, which indicates a higher quality factor and a sharper resonance peak. As mentioned earlier, this may potentially help in resolving minute changes in refractive indices. Our results reveal that the proposed structure can achieve more than 60% reduction in FWHM compared to regular, topologically unordained GMR structure.

In conclusion, we have proposed a novel GMR structure that is enhanced by topological photonics. COMSOL Multiphysics has served as an excellent tool, providing reassurance through result consistency when reproducing published findings. The designed device can potentially serve as a unit in an on-field environmental monitoring system. The work may be extended to gas sensing with related modifications.

Figures used in the abstract

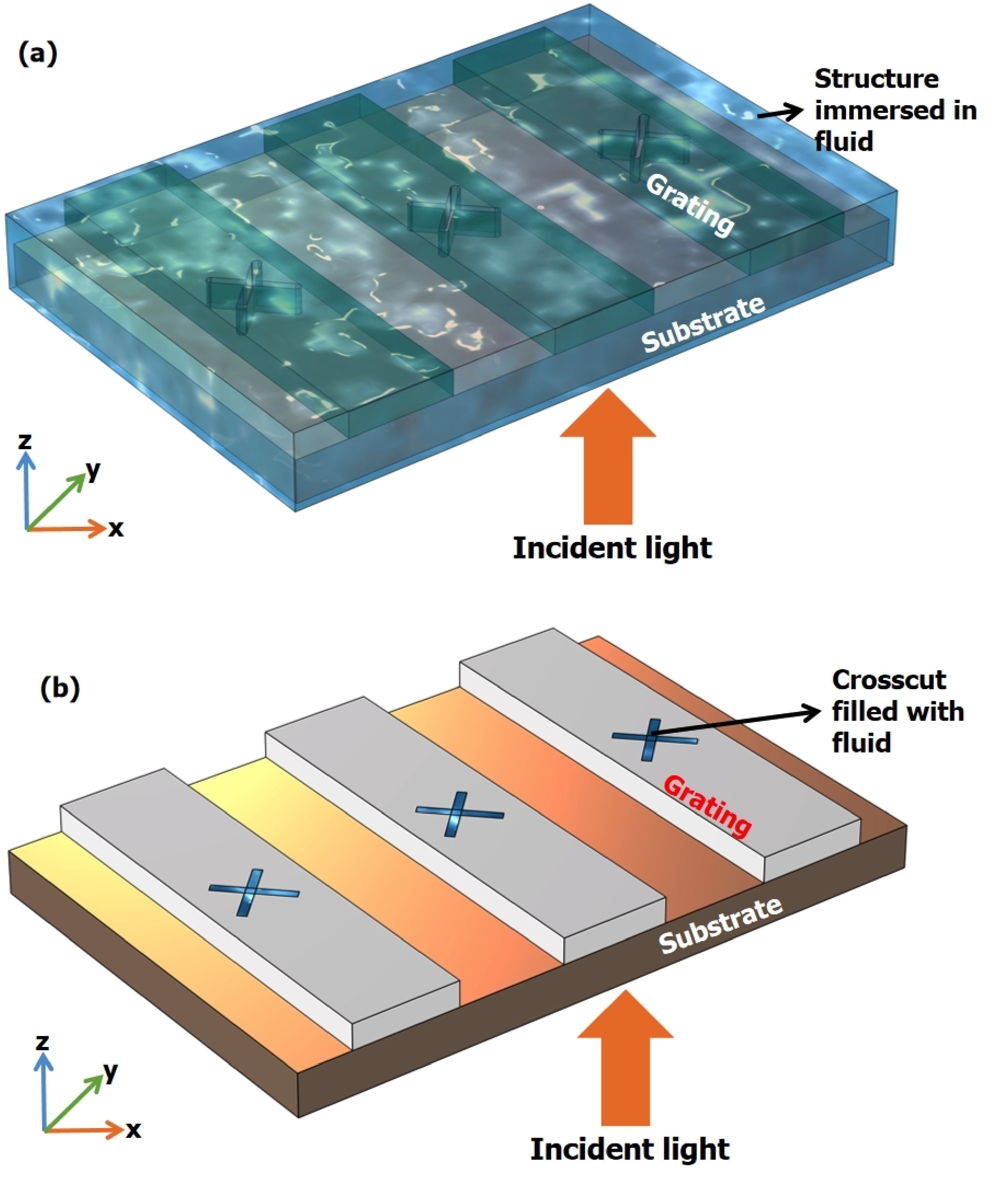
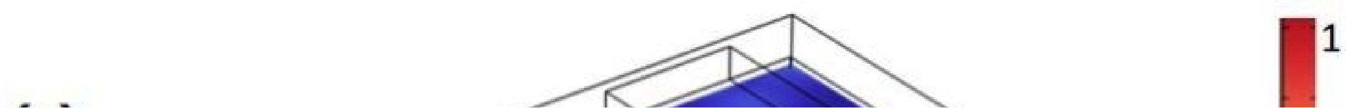
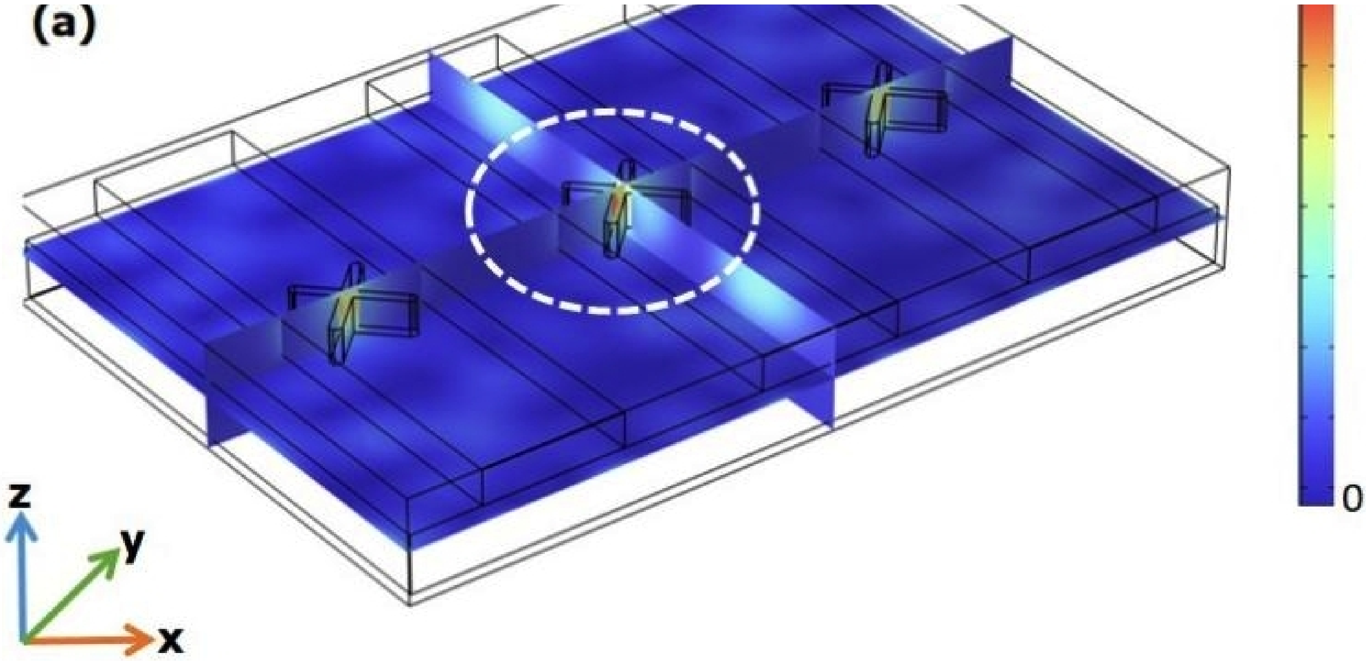
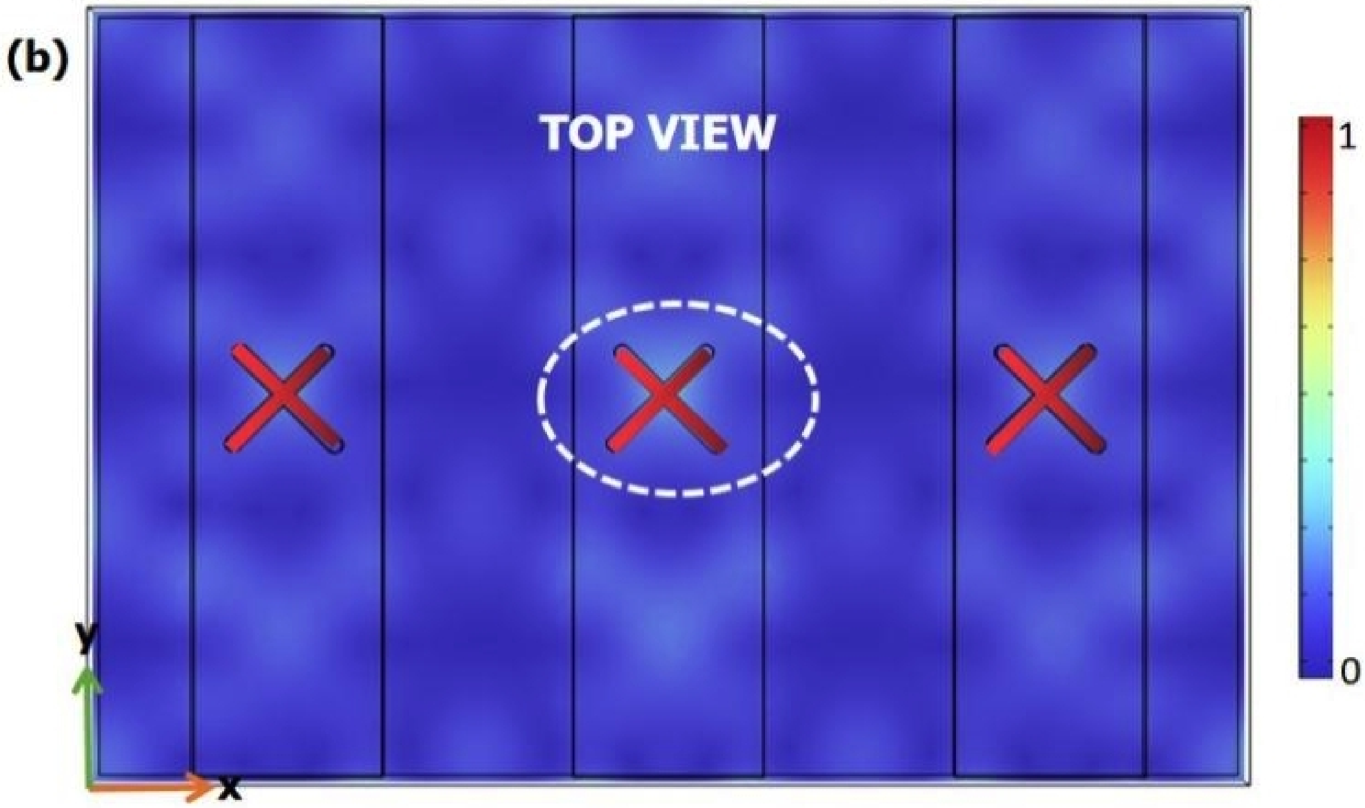
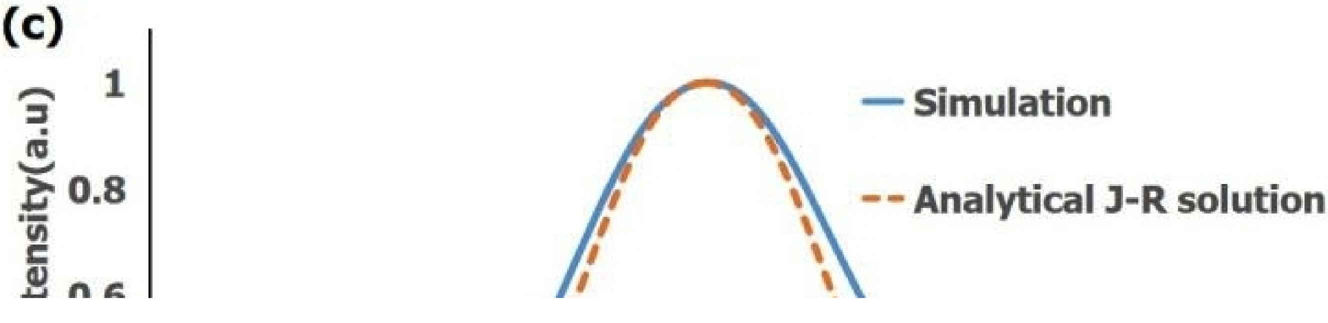


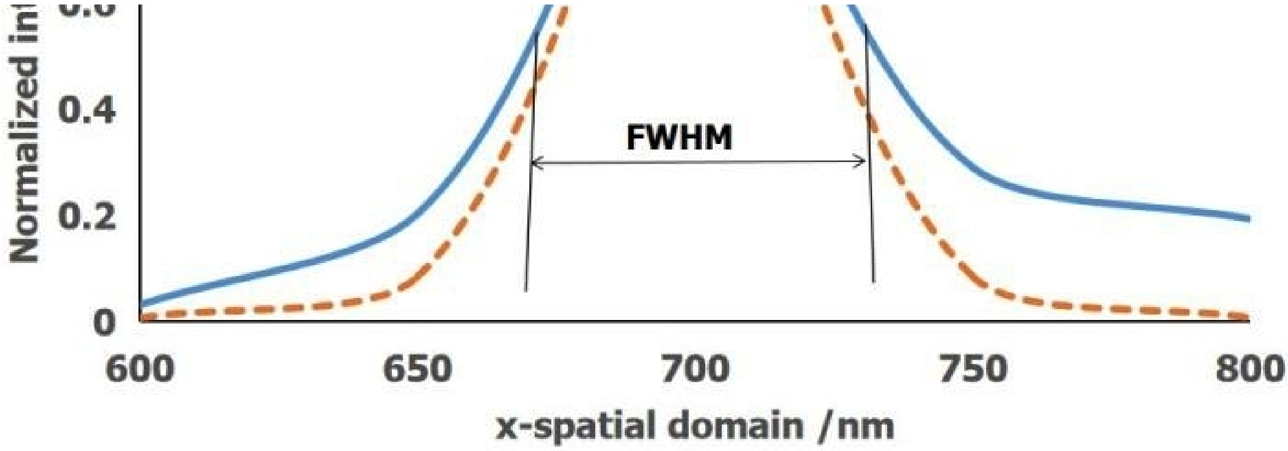
Figure 1 : (a) Topological guided mode resonance structure immersed in fluids (b) only the crosscut is filled with fluid (Fluids considered for analysis - water, ethanol, propyl, petrol, diesel, glycerol)




(a)
0
z
y
x


(b)
TOP VIEW
1
0
y
x


(c)
1
0.8
Simulation
Analytical J-R solution



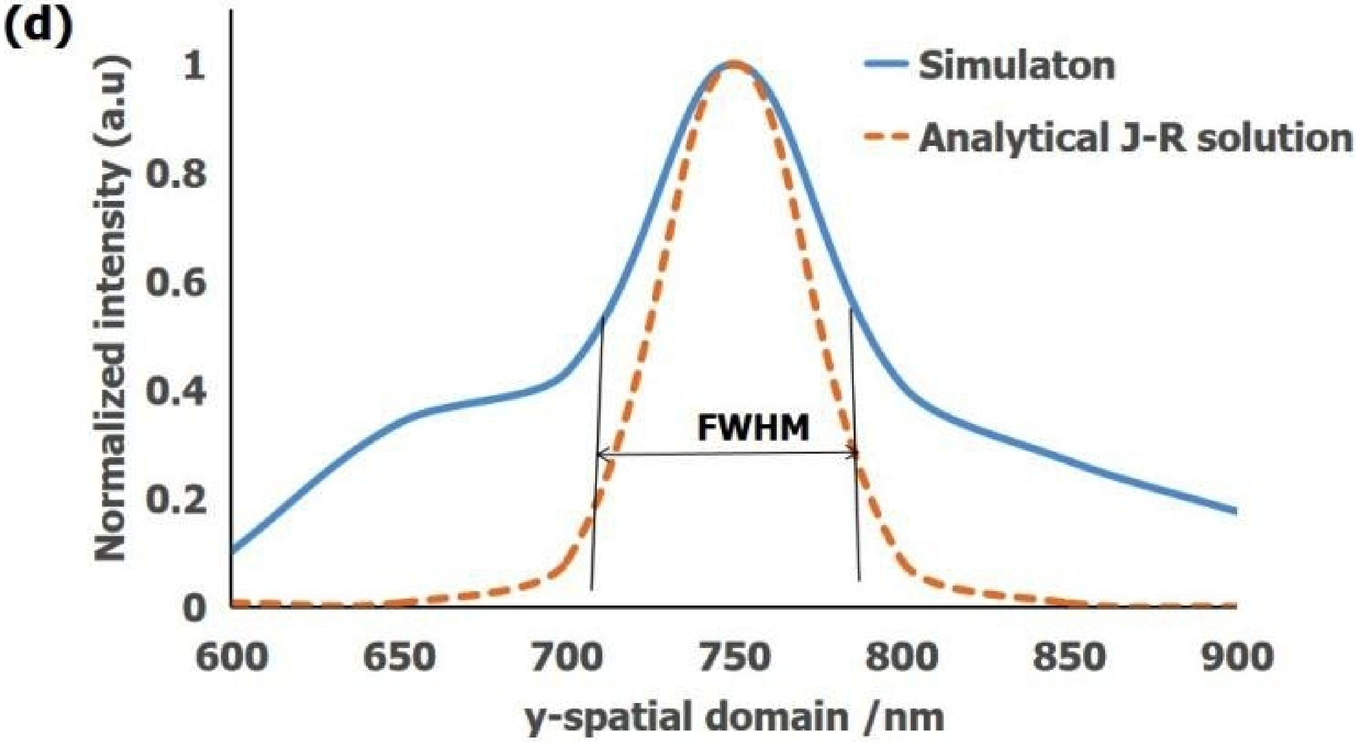
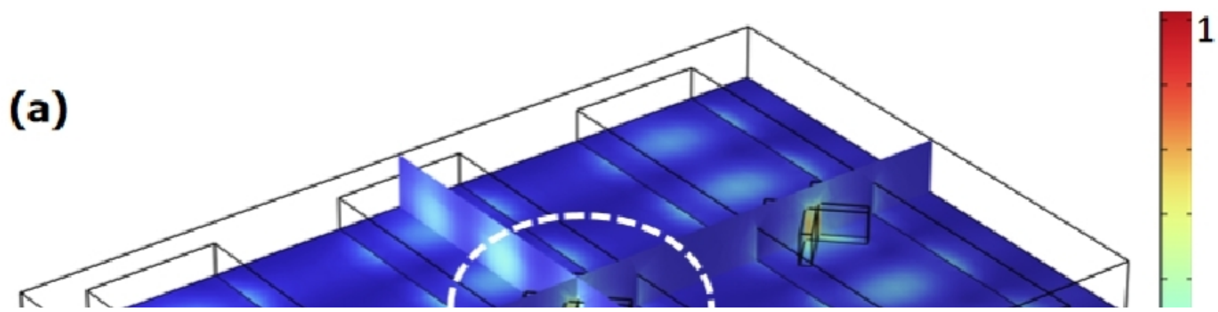
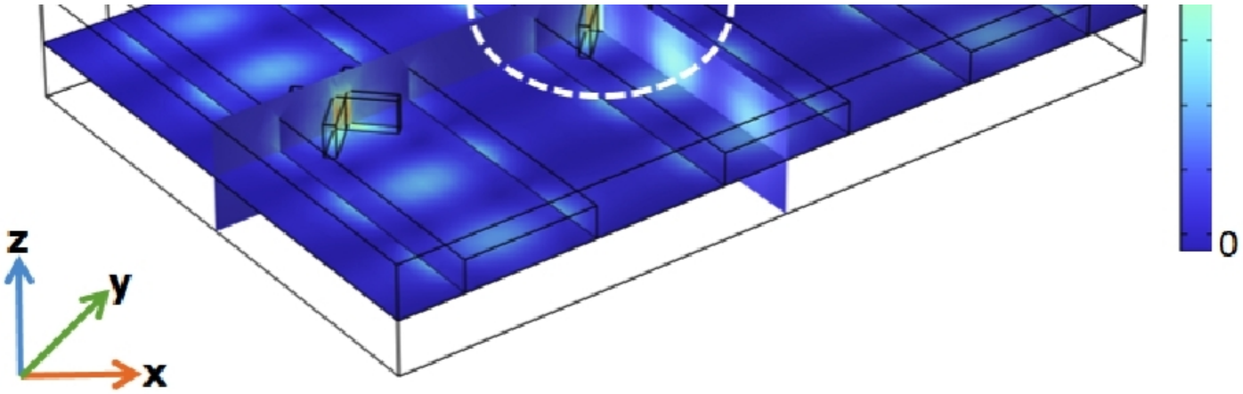


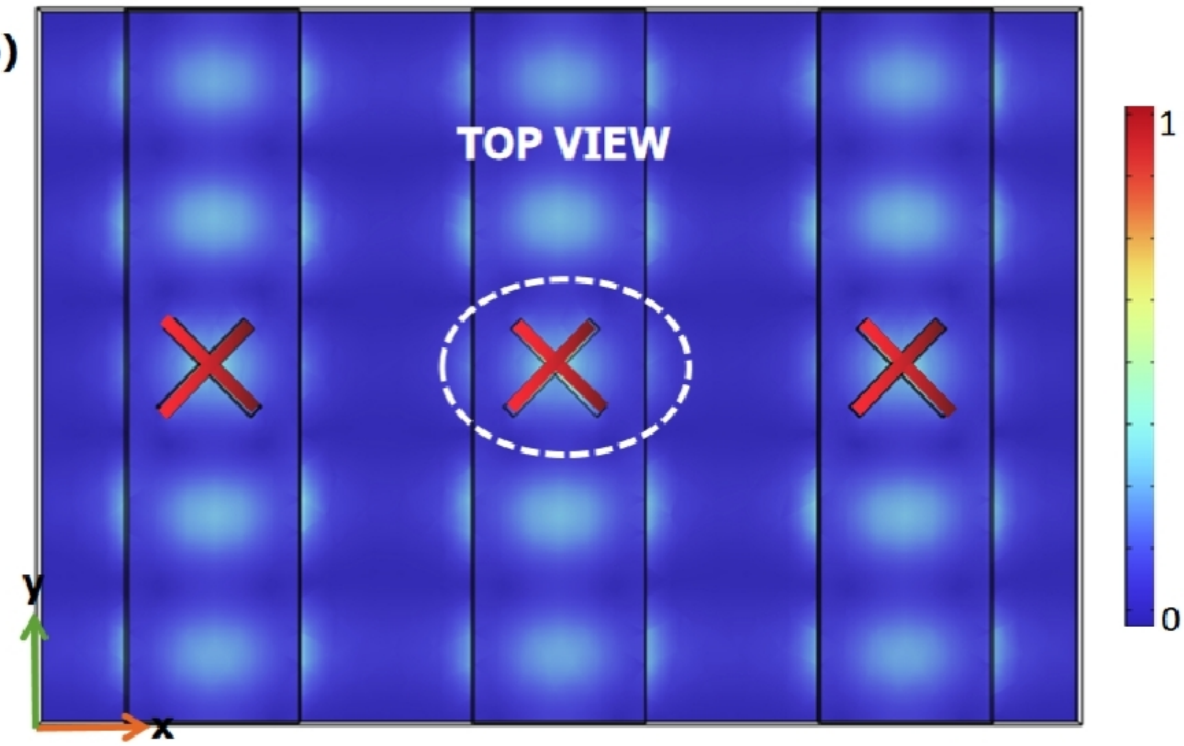
Figure 2 : (a) Optical field confinement in the surface enhanced topological GMR structure immersed in fluid at 670nm (b) top view of the proposed structure and red region indicates highest field confined (c) Normalized intensity plot with respect to JR equation a





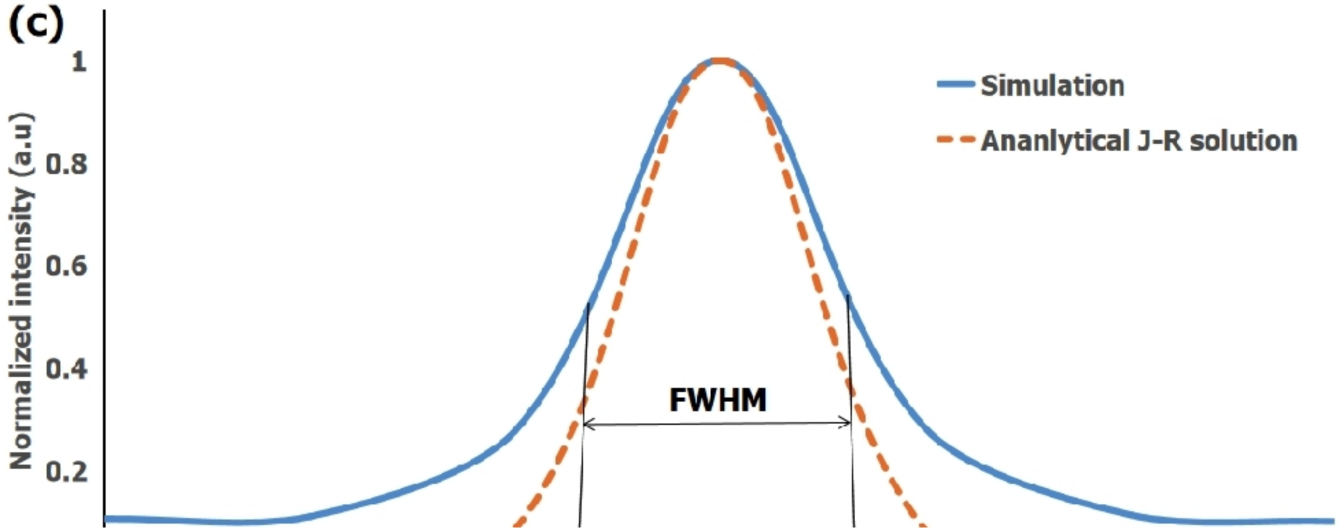
z
y
x
0

(b)

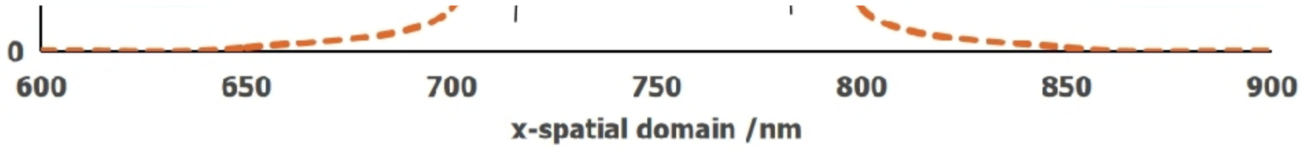


TOP VIEW
1
0
y
x

(c)



Normalized intensity (a.u)
1
0.8
0.6
0.4
0.2
FWHM
Simulation
Ananlytical J-R solution



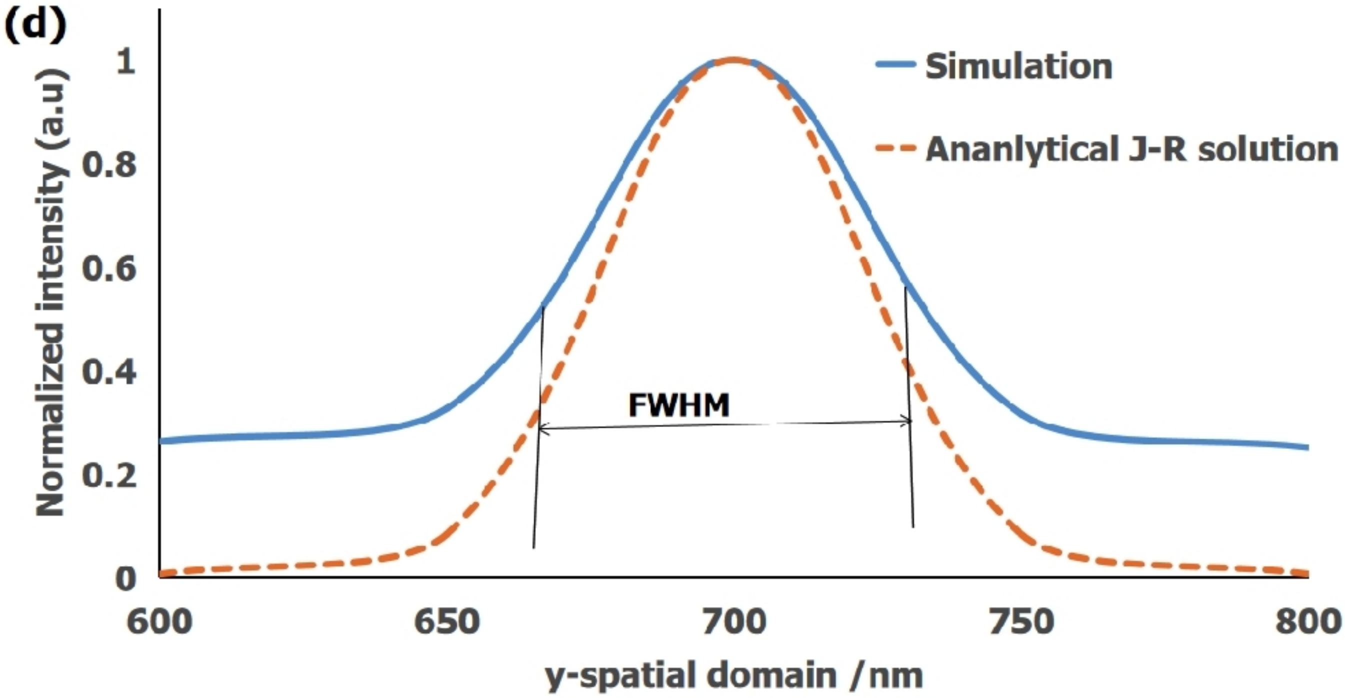


Figure 3 : (a) Optical field confinement in the surface enhanced topological GMR structure, crosscut filled with fluid at 650nm (b) top view of the proposed structure and red region indicates highest field confined (c) Normalized intensity plot with respect to JR

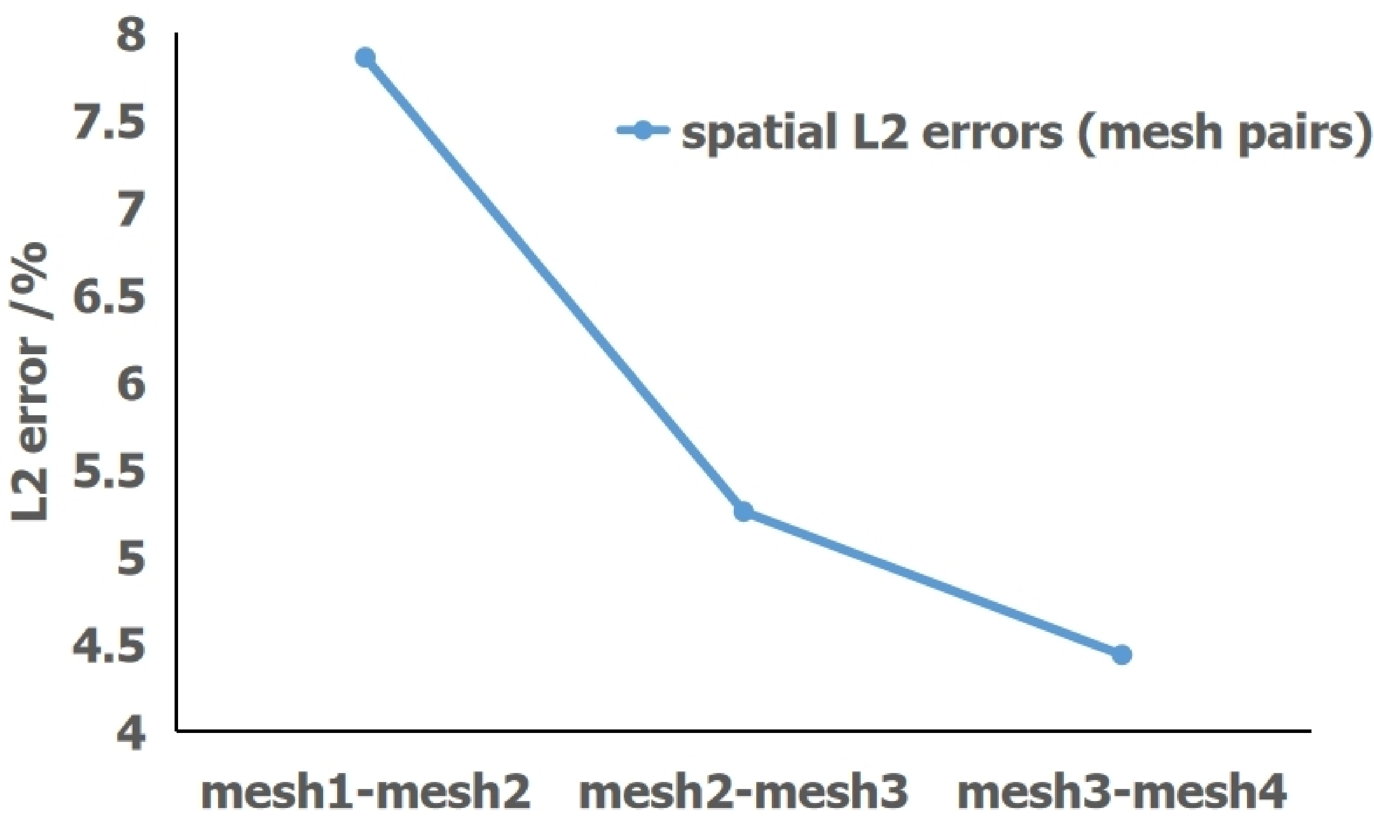


Figure 4 : L2 errors of proposed design for mesh pairs