Development of Software to Explore the Optical Properties of Multilayers

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Computational Science

Objectives

The objectives were to develop computational tools to model the optical properties of multilayers, specifically:

- To calculate the reflection, transmission, and cross-sectional electromagnetic field profile of multilayers consisting of dielectric or metallic thin films.
- Constructing an algorithm to optimize the design of multilayers that exhibit Bloch surface waves.
- Implementing a basic front end user interface.

Introduction

Bloch Surface Waves (BSWs) occur in a multilayer when resonance is achieved between an incident electromagnetic wave and a surface guided wave in the defect layer. BSWs are non-radiative and are only generated in a prism coupling arrangement at incident angles beyond the critical angle for total internal reflection. The result is a dip from total reflection to near-zero reflection at certain "resonant angles."

The resonant angles are highly sensitive to the conditions at the surface. Placing a sample on the surface significantly alters the resonant angle, allowing for measurements of nanoscale biochemical processes such as antigen-antibody reactions. The overall goal of the project is to design multilayers that exhibit optimal BSW properties for biosensing applications.

Methods & Results

All code was written in Python. The matrix method outlined in Ohta and Ishida [1] was implemented to compute the coefficients of reflection and transmission for the designed multilayers. Algorithms were created to explore various combinations of refractive indexes and layer widths for optical multilayers. The code was executed on personal laptops and the MTSU CS JupyterHub clusters.

The optimization algorithms found multilayers exhibiting BSWs with sensitivities of 3.4 degrees per RIU, which is a slight improvement over older designs. A design with a sensitivity of 18.3 degrees per RIU was found, but it does not seem to exhibit a BSW, which means that the observed reflectivity dip is due to interference and not resonant coupling. SWT measures were similar with RIU measures.

Multilayer Diagram

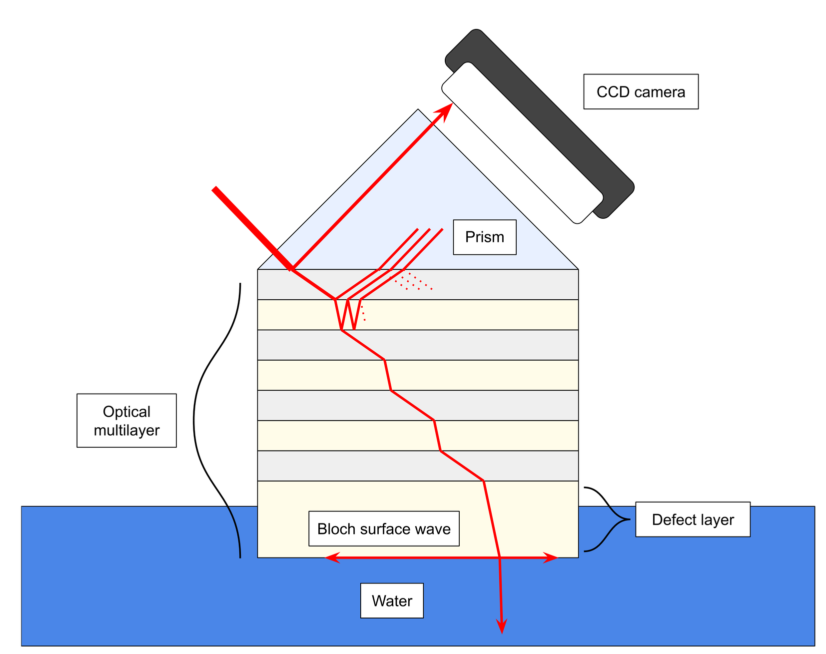

Figure 1: Diagram of a cross-sectional view of an optical multilayer setup. The net reflectivity of the layer can be physically measured by placing a CCD camera as shown.

Physical Demo

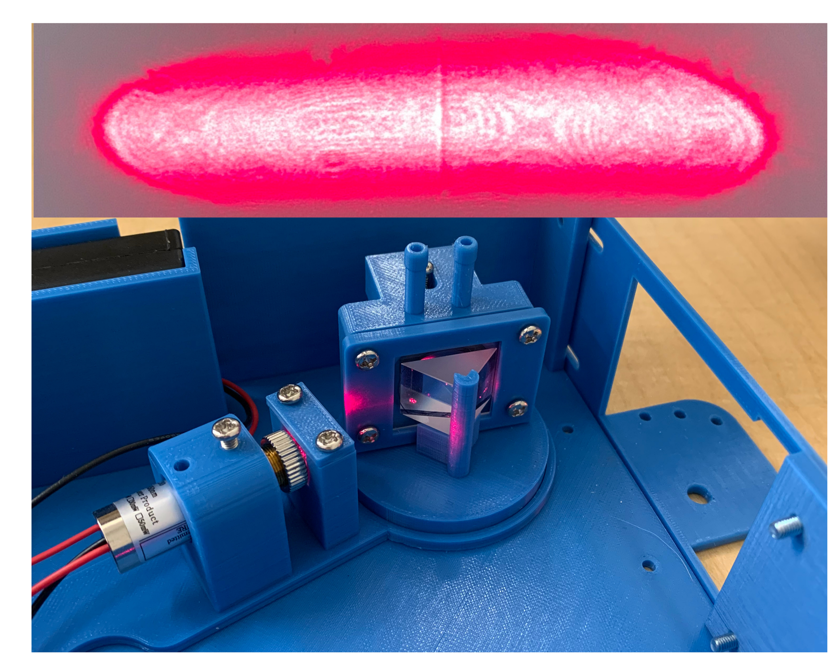

Figure 2: Picture of an inexpensive physical demo of BSW resonance, containing a laser and optical multilayer embedded in a 3D printed frame.

Electric Field Profile

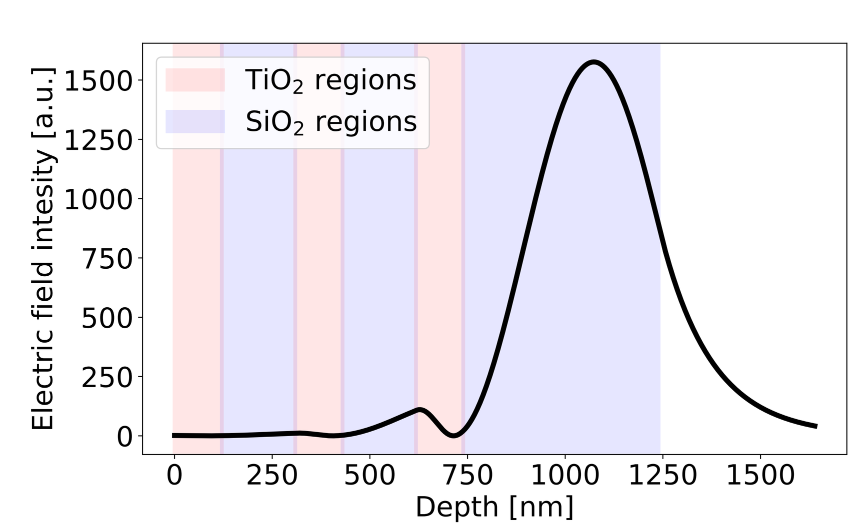

Figure 3: Electric Field profile throughout the multilayer, showing the BSW in the defect layer.

Reflectivity With Angle

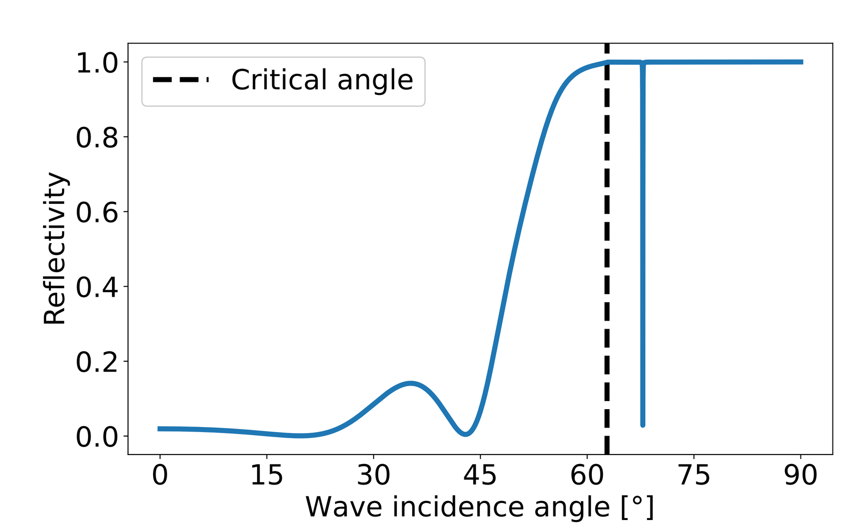

Figure 4: Diagram showing the reflectivity dip caused by a BSW

Conclusion

The created algorithms are successful and efficient at identifying optimal multilayer designs. The codebases were uploaded to Github, providing interactive frameworks to utilize the tools. Future plans include placing the code into a Python module to be uploaded to the Python Package Index, allowing other researchers to import the functionality into their own code. Multilayers with defect layers in different positions and different materials will be explored to determine if even more optimal designs are possible.

References

[1] Koji Ohta and Hatsuo Ishida. Matrix formalism for calculation of electric field intensity of light in stratified multilayered films. *Applied optics*, 29:1952–9, 05 1990.

Contact

- Github 1: `https://github.com/davidcheson/optical_multilayer`
- Github 2: `https://github.com/jliu168/multilayer`
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Acknowledgments

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