COMSOL CONFERENCE TOKYO 2012

A-3

COMSOL Multiphysicsによる金属/誘電体/金属(MIM)薄膜構造の可視域・分光反射特性の解析

Visible Spectral Reflectance Analysis in Metal-Insulator-Metal (MIM) Multilayer by COMSOL Multiphysics

押鐘　寧（Yasushi Oshikane）

大阪大学　大学院工学研究科

Division of Precision Science & Technology and Applied Physics,
Graduate School of Engineering, Osaka University,
2-1 Yamada-oka, Suita, Osaka 565-0871 Japan

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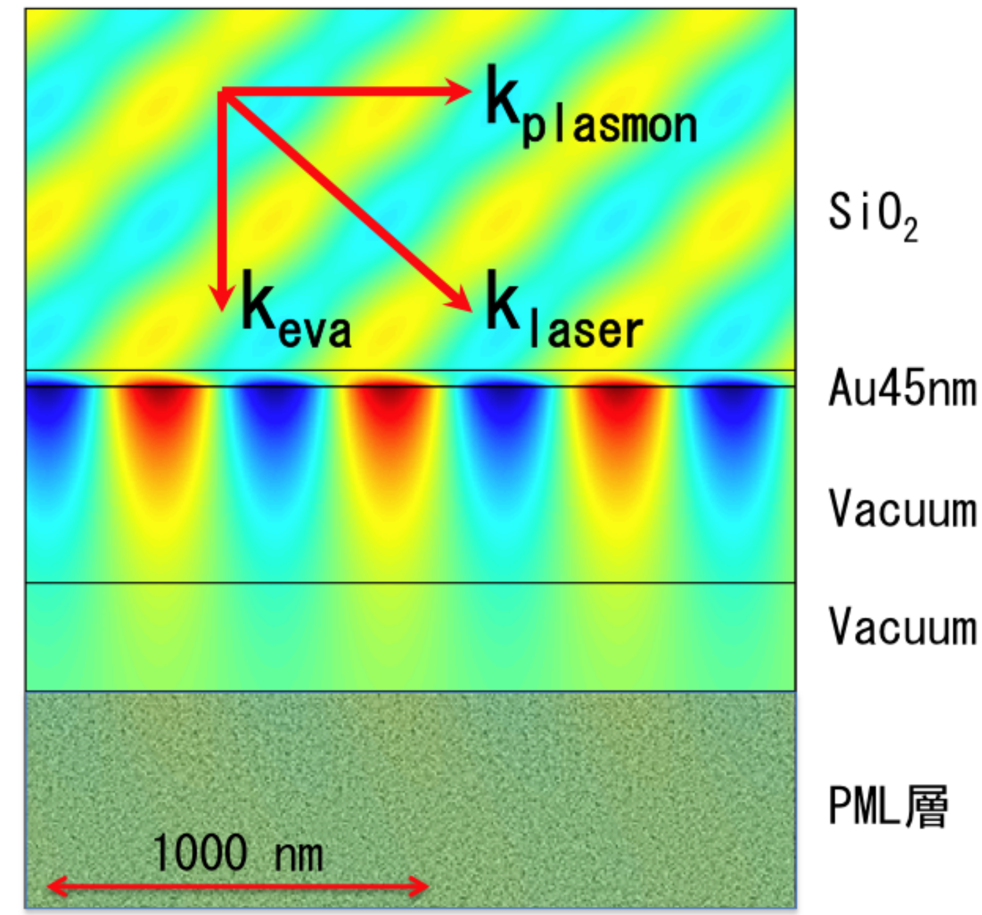
講　演　要　旨

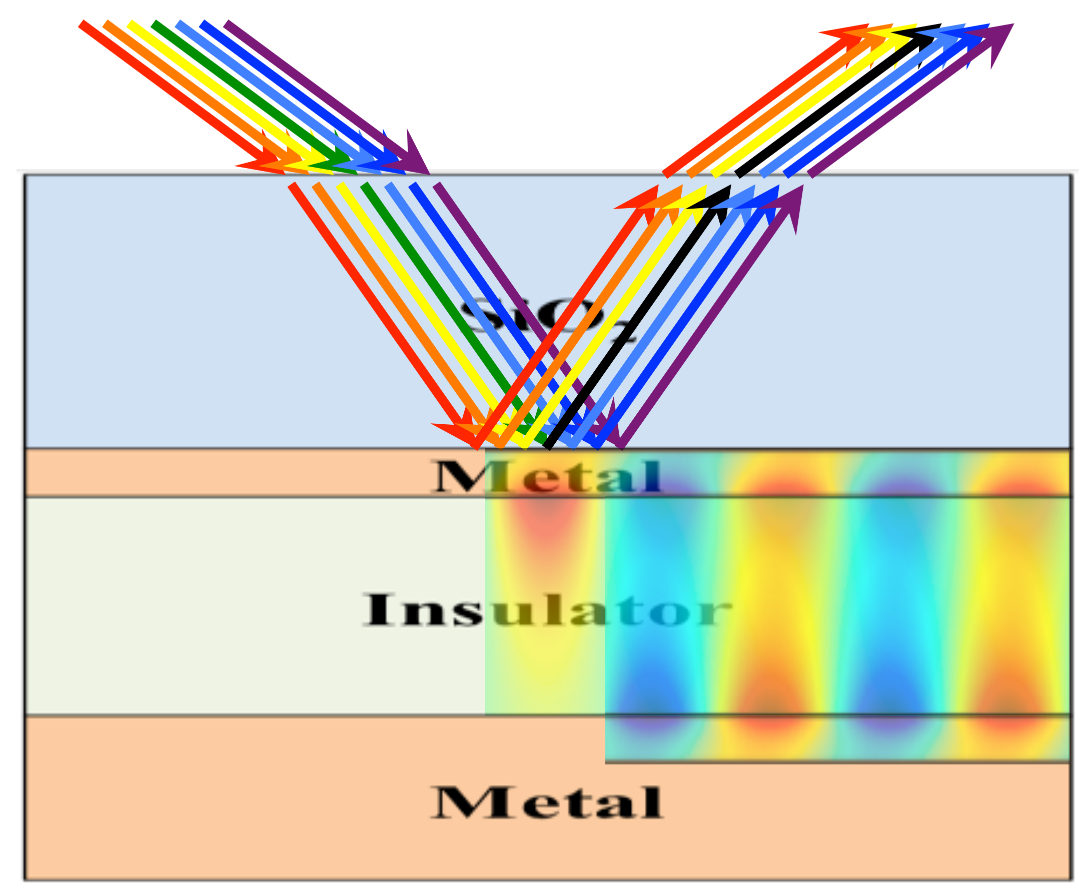
可視域での，波長幅の狭い吸収特性を有する反射型MIMフィルタの開発を行なっている．この構造は，各層の厚みが光波長以下，最小λ/10程度であるため，反射特性を誘発する光波と薄膜との電磁場相互作用，特別な条件下でのみ励起される表面プラズモン共鳴現象の理解に数値シミュレーションが欠かせない．本講演では，COMSOL Multiphysics + RF Moduleによるそうした電磁場現象の解析結果を実験結果とともに報告する．

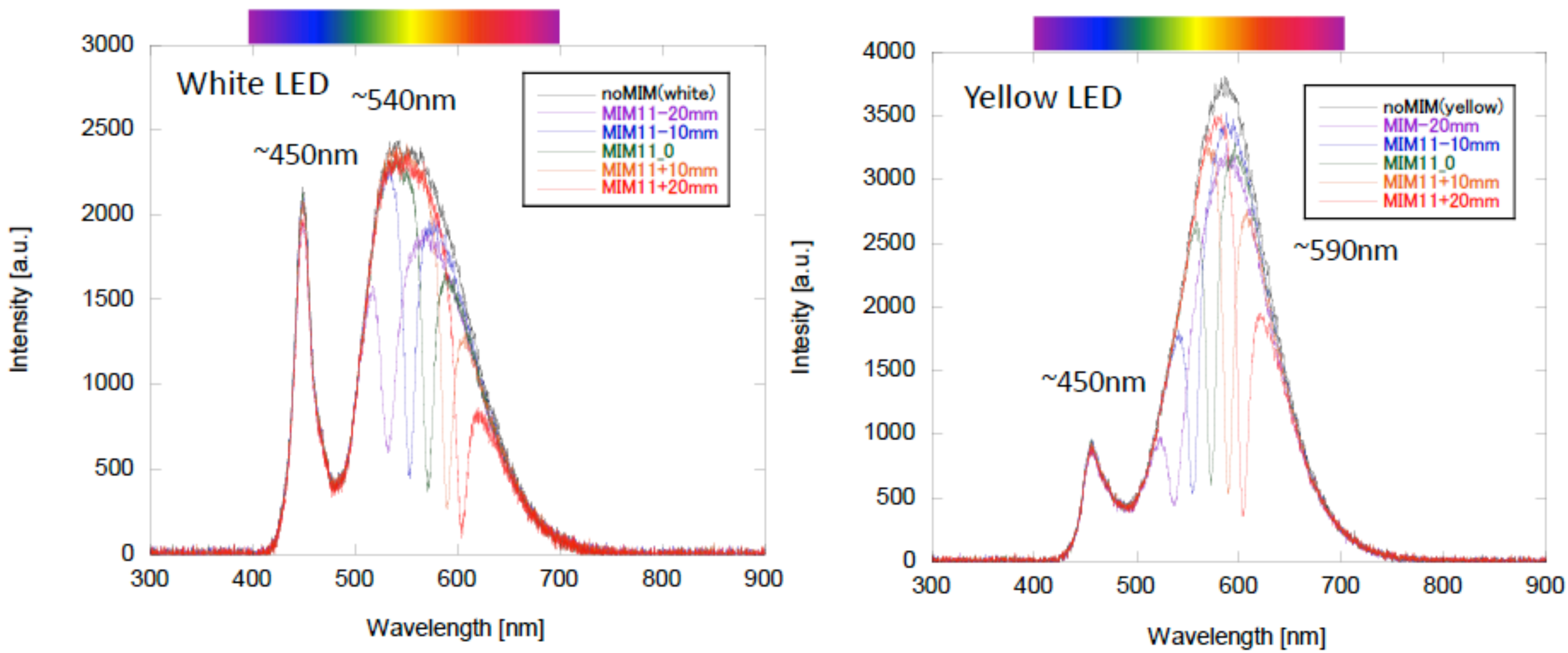
ABSTRACT

We have started to develop a reflective metal-insulator-metal (MIM) filter with a narrow band absorption. In the MIM structure, an interaction between subwavelength multilayer and visible light, and resultant surface plasmon resonance (SPR) in specific illumination condition must be understood. Such electromagnetic field interactions have been analysed by COMSOL Multiphysics and RF Module.


白色LED照明

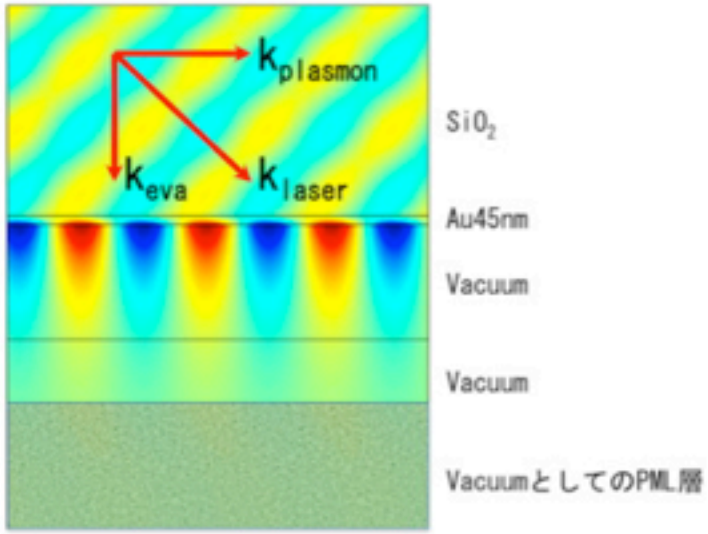

$k_{plasmon}$
k_{eva}
k_{laser}
SiO_2
Au45nm
Vacuum
Vacuum
PML層
1000 nm

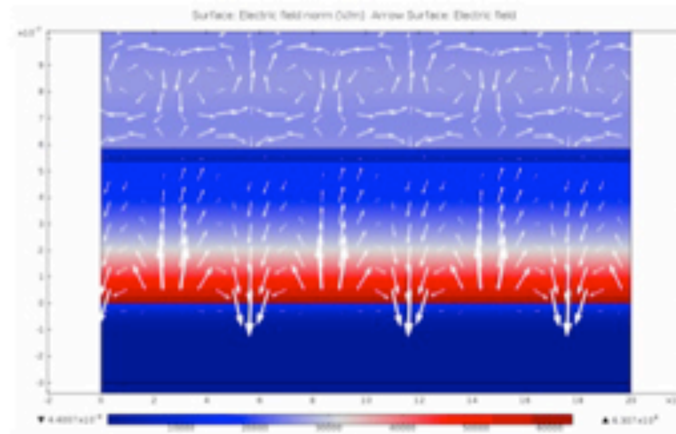

Metal
Insulator
Metal

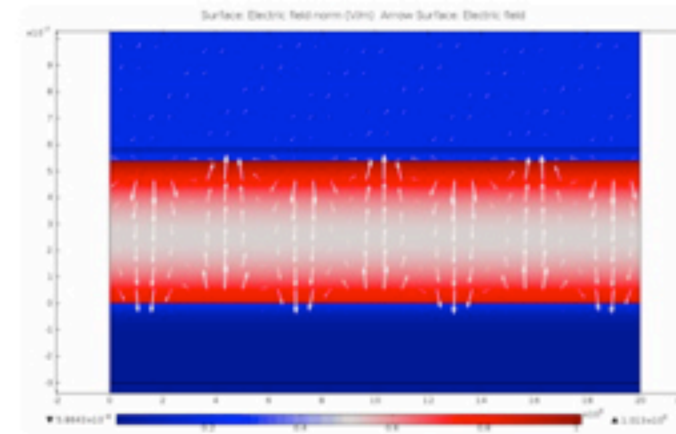


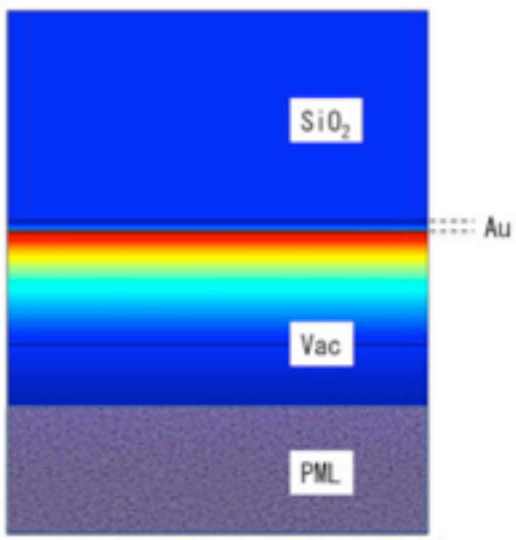
Relation between white and yellow LED spectra and several absorption dips

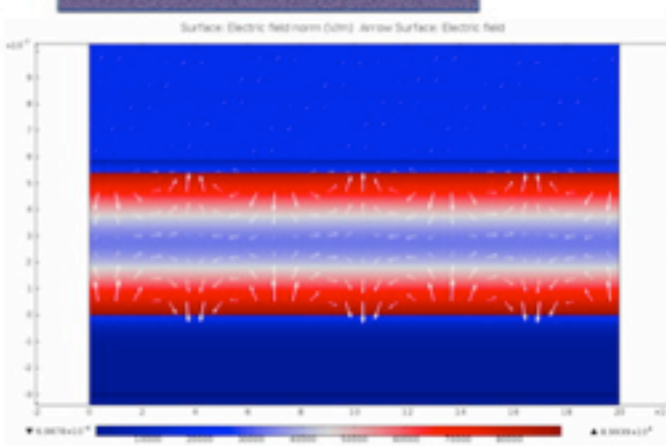
FEM simulation of EM waves in MIM structure

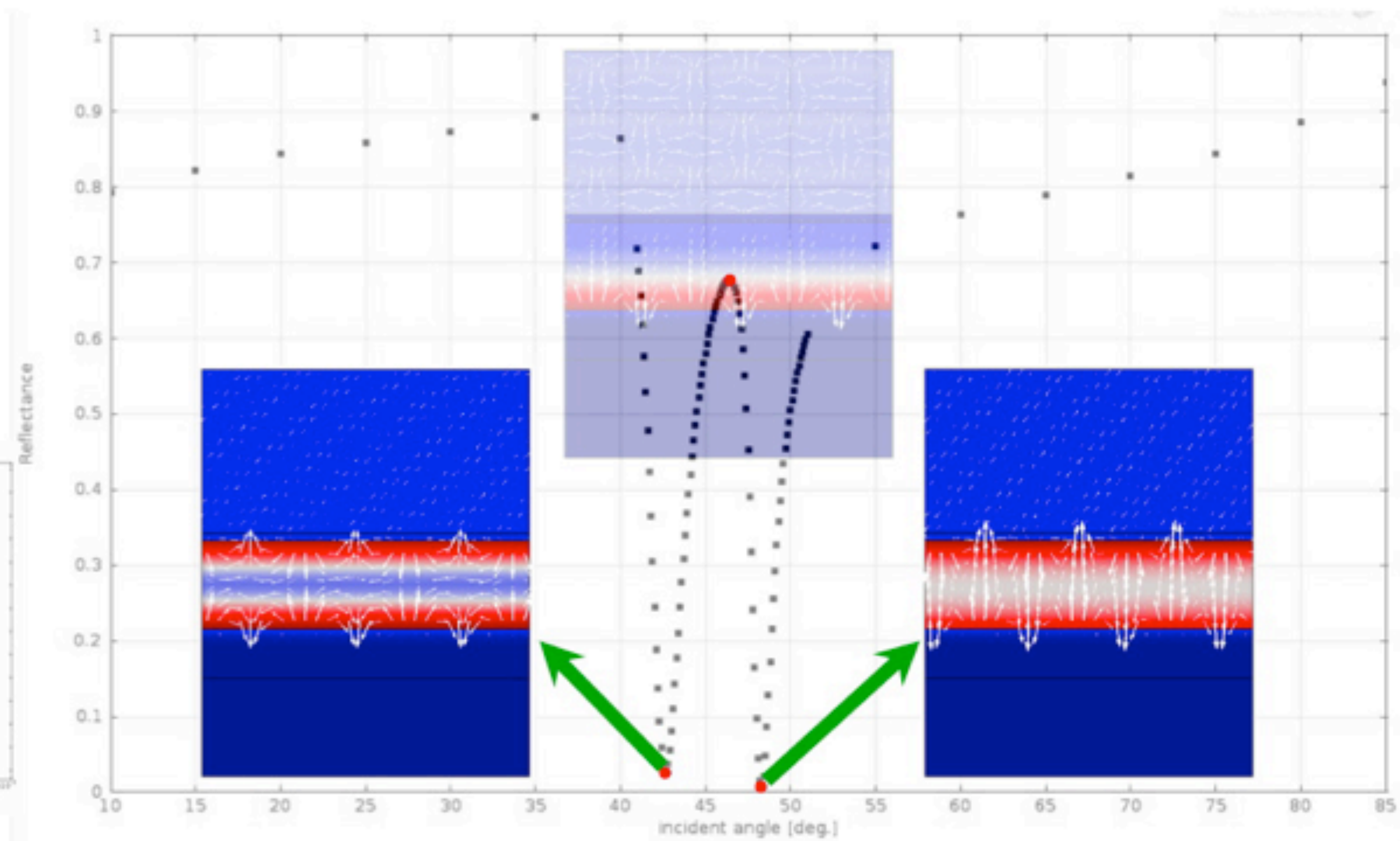




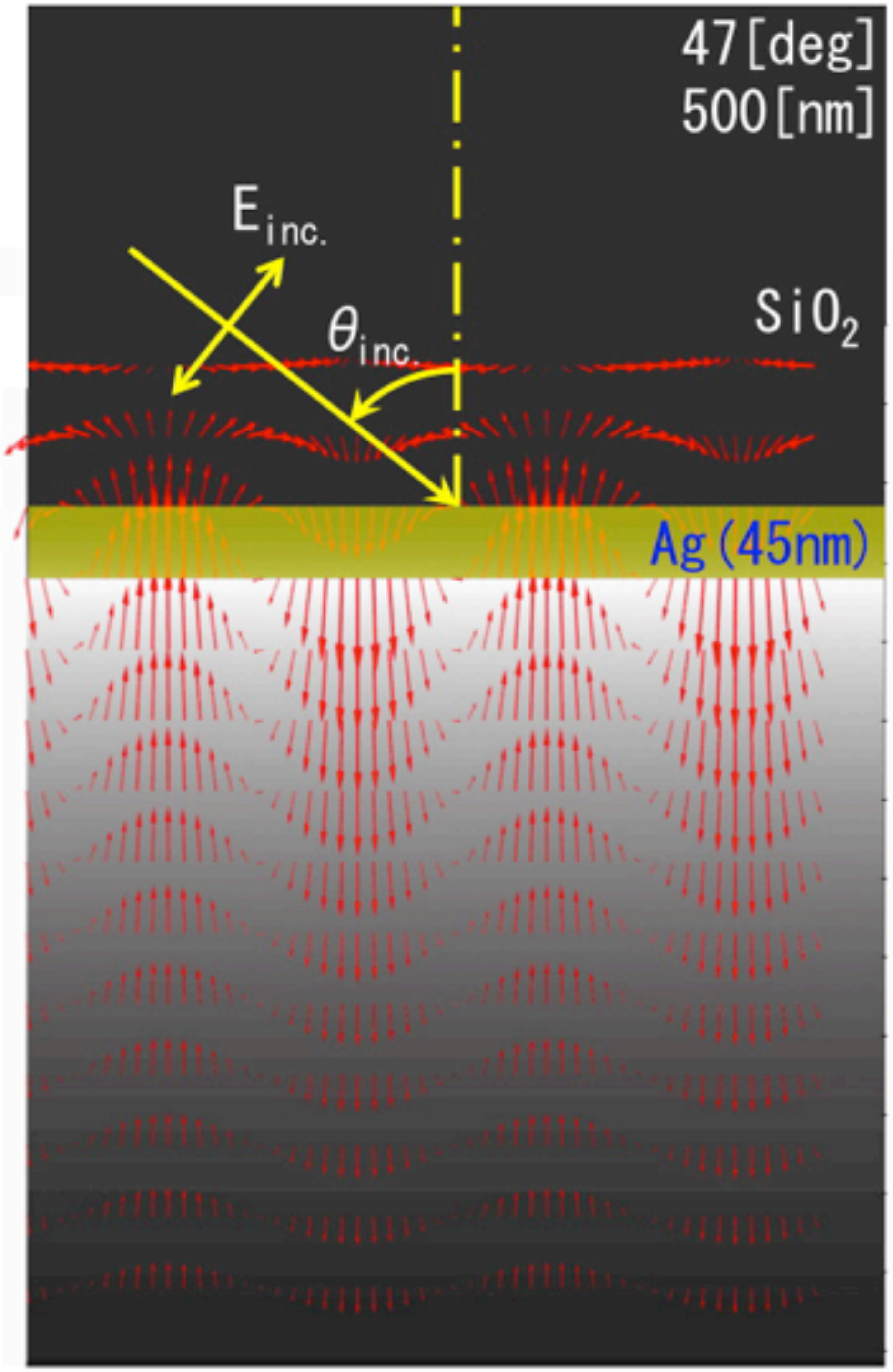


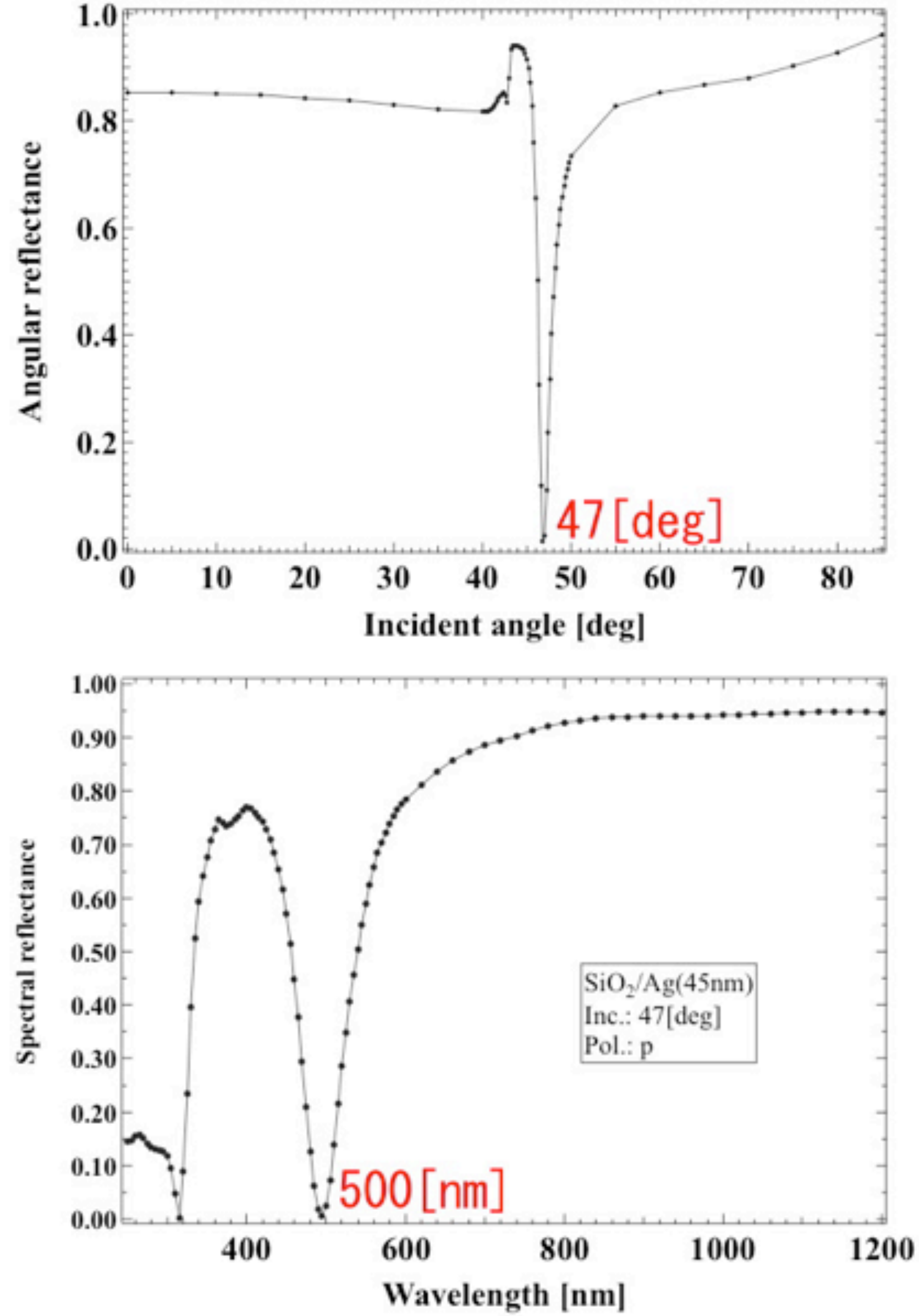


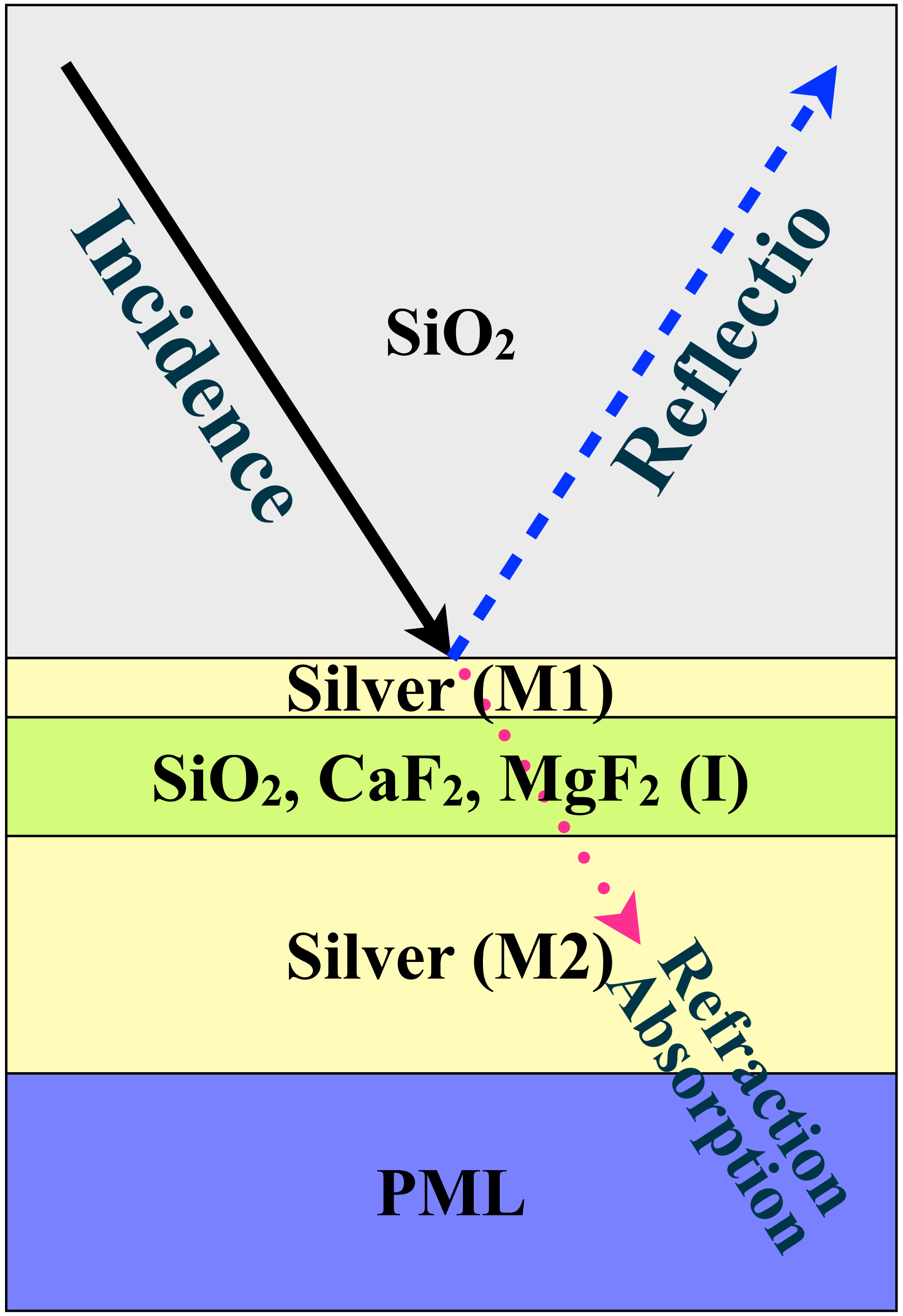




Surface plasmon resonance(Ag:45 nm)







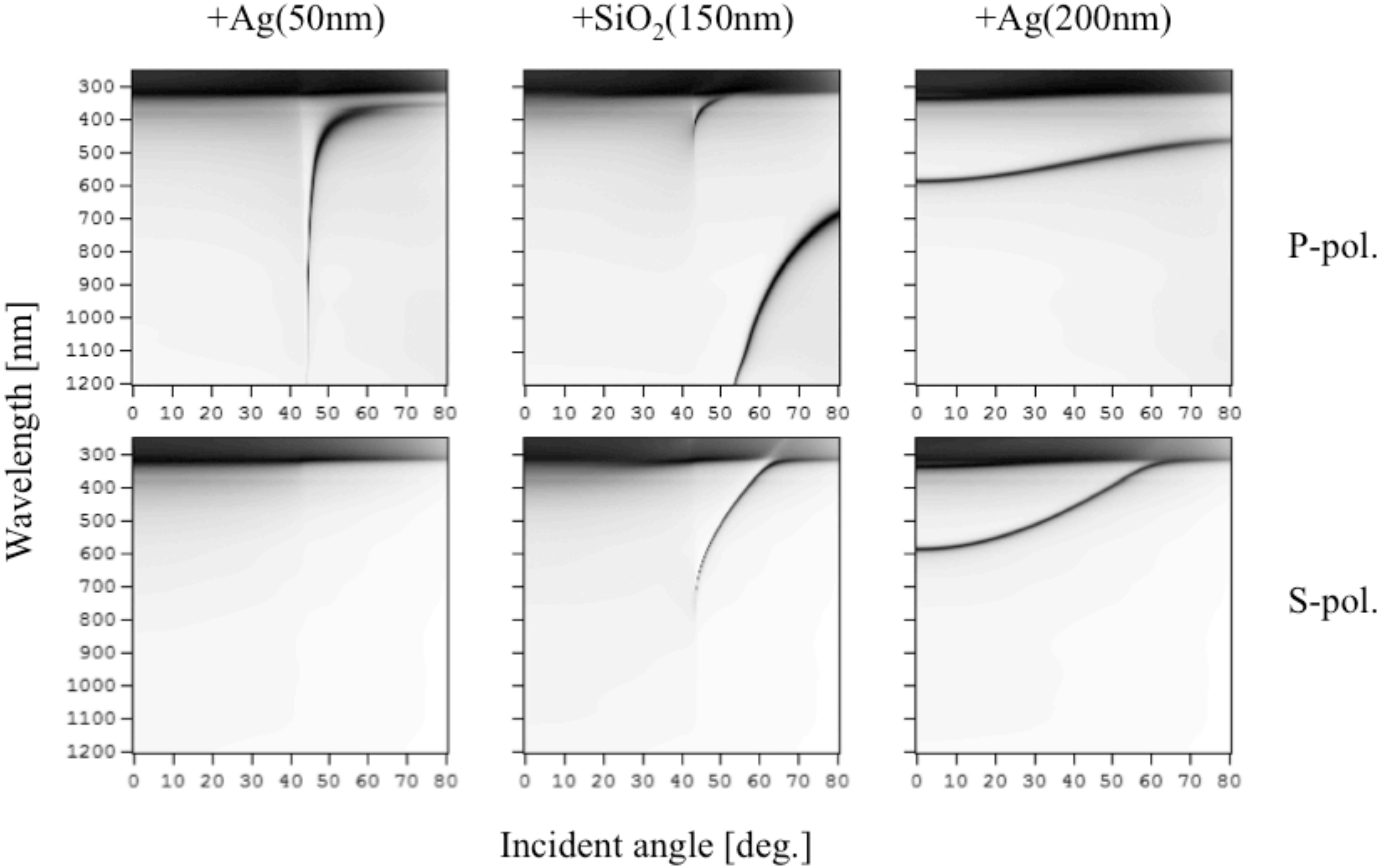
INCIDENT LIGHT WAVE

Wavelength : 250 to 1200 nm
Polarization : P and S
Incident angle: 0 to 80°

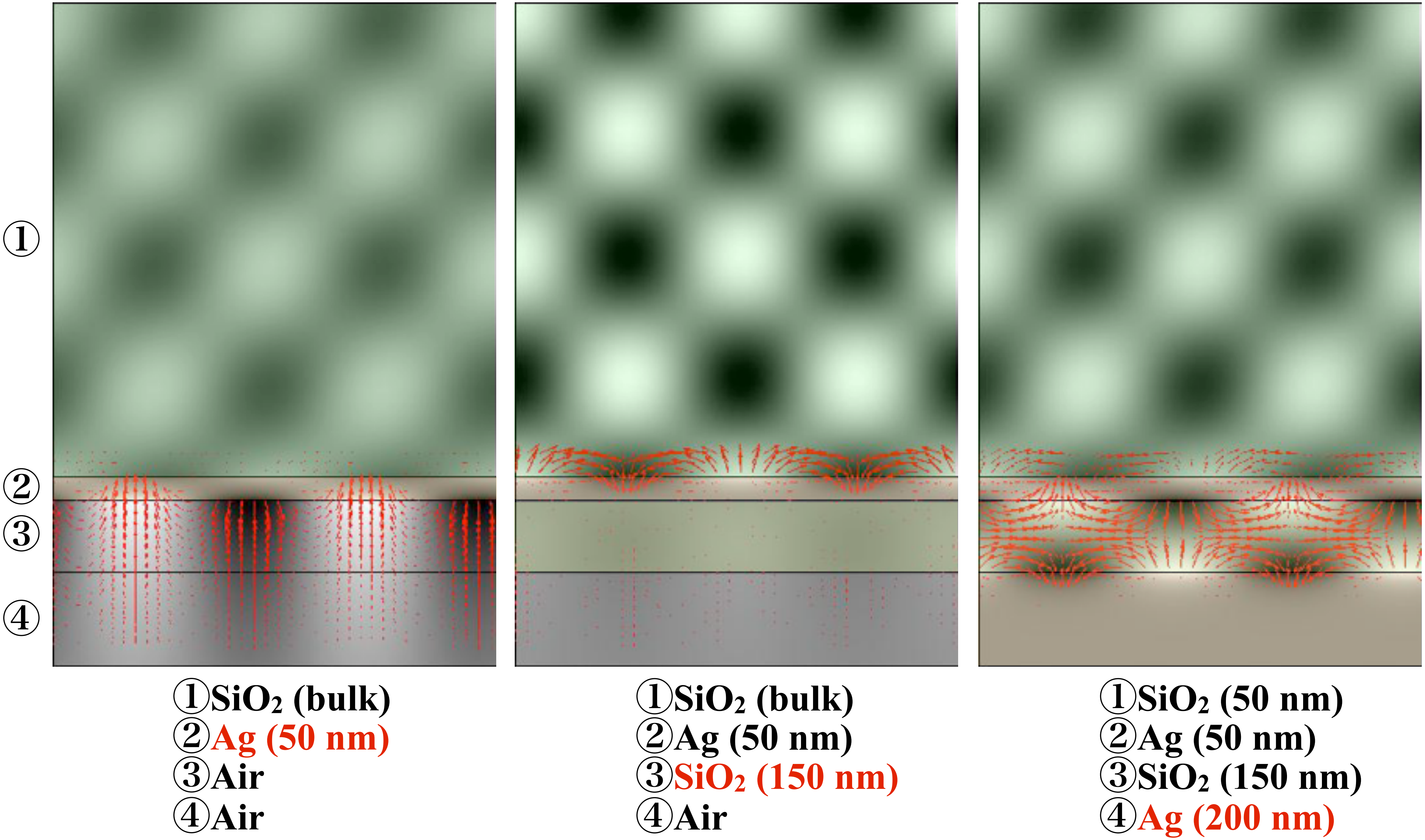
MODEL STRUCTURE (2D MODEL)

1st layer : SiO_2
2nd layer(M1): Ag 50 nm (Au)
3rd layer(I) : SiO_2 150 nm (CaF_2, MgF_2)
4th layer(M2): Ag 200 nm (Au)
5th layer : PML(No reflection)
Dimension : H=2500 nm, W=2000 nm

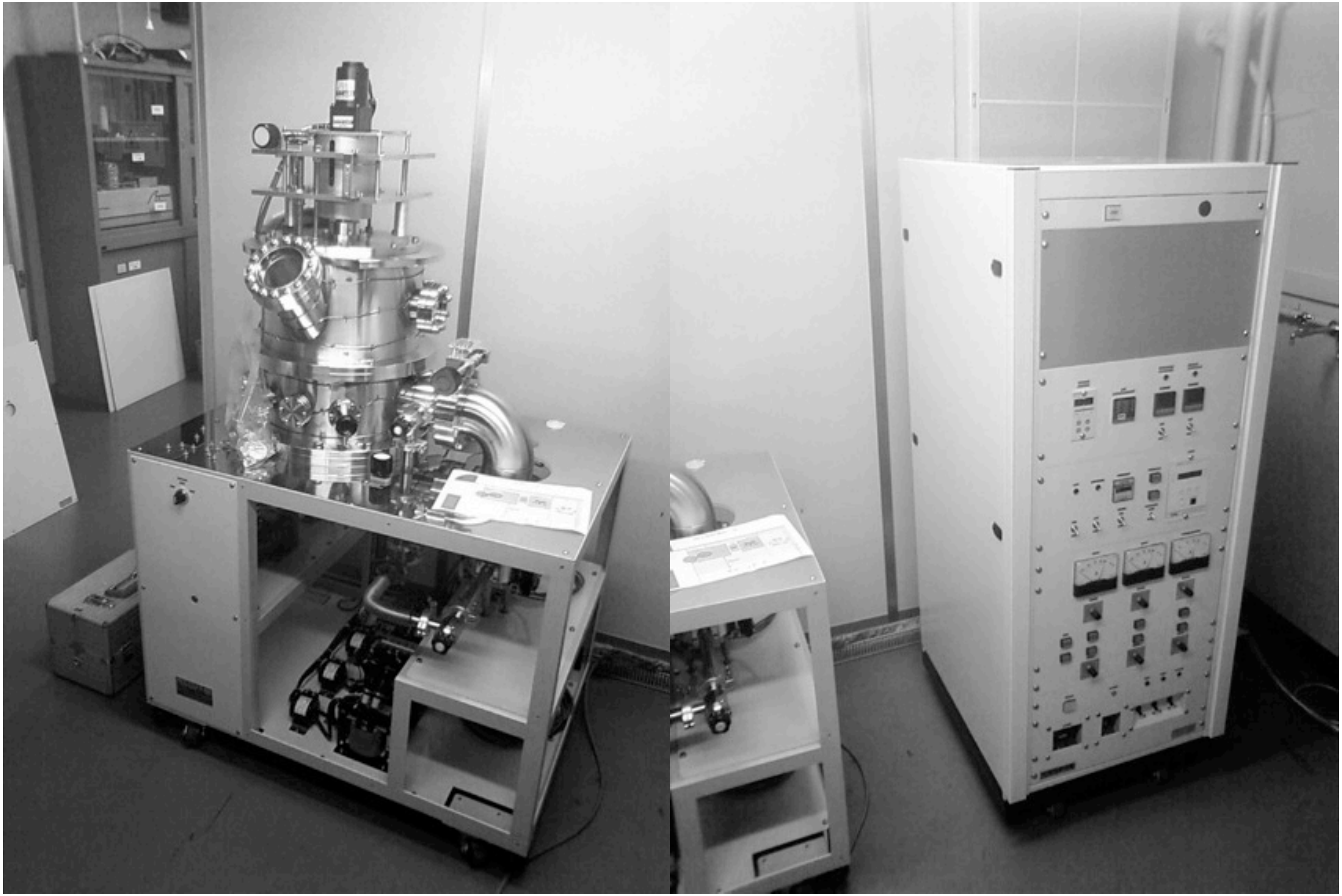
Numerical model used in 2D FEM simulation for understanding of MIM absorption dip. Each domain is divided into fine triangular elements which are smaller than λ/10.



Transfer matrix calculation of angular-dependent spectral reflectance in fabrication of MIM structure. The top and bottom maps show calculations for P- and S-polarized light, respectively. The grayscale ranges from black (representing 0% reflectance) to white (representing 100% reflectance).

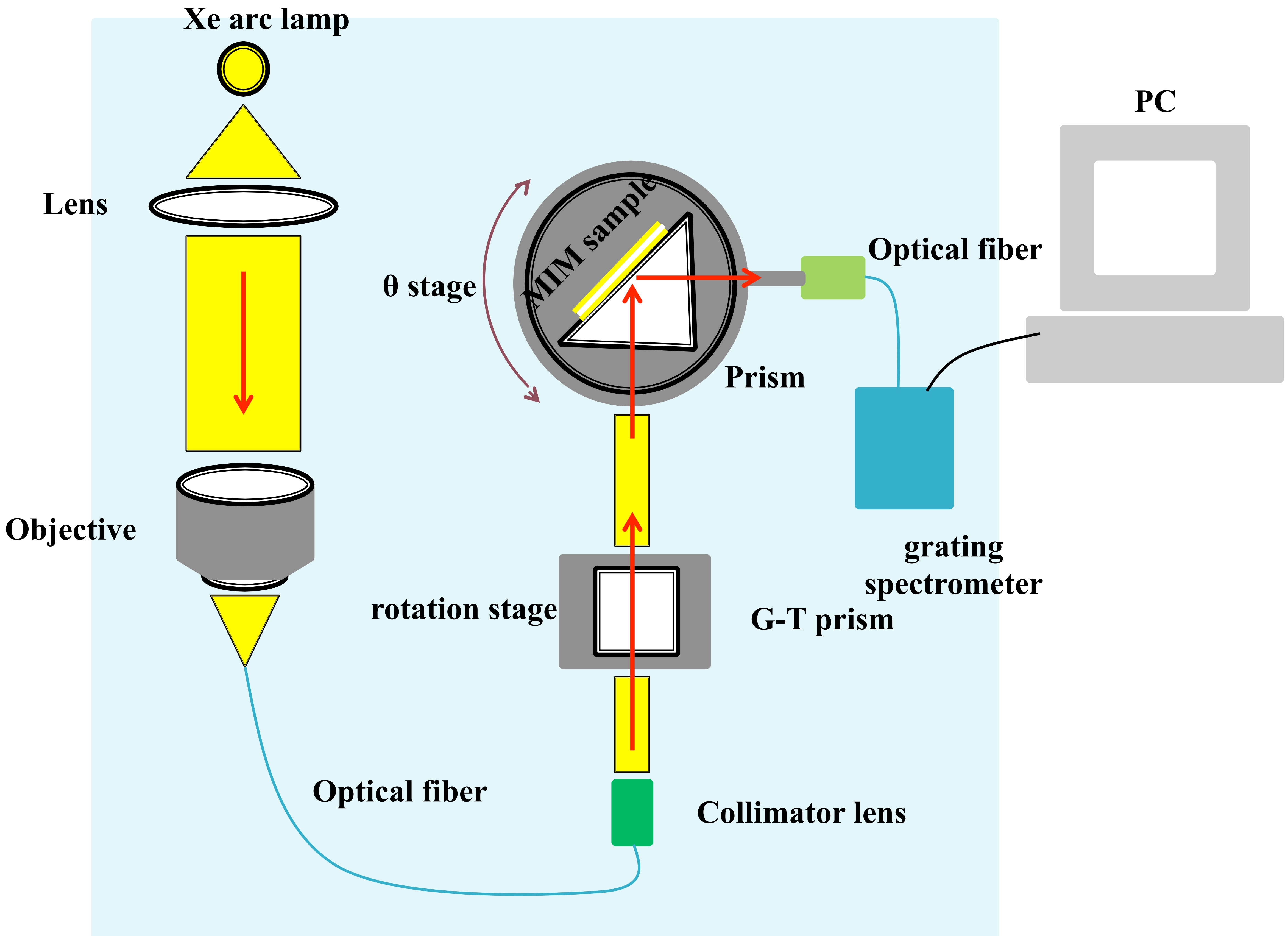


2D FEM calculations for (M (+ I (+ M))) structures corresponding to maps indicated in Fig. 2. The grayscale pattern shows the electric field |E| distribution within the structures, and red arrows indicate E vectors surrounding the thin layers. The left, middle, and right maps correspond to normal SPR, a kind of IMI, and MIM configurations, respectively. P-polarized light at 500 nm with an incident angle of 50° from surface normal impinges the sample from the upper left direction, and the incident and reflected waves form a checkered interference pattern.

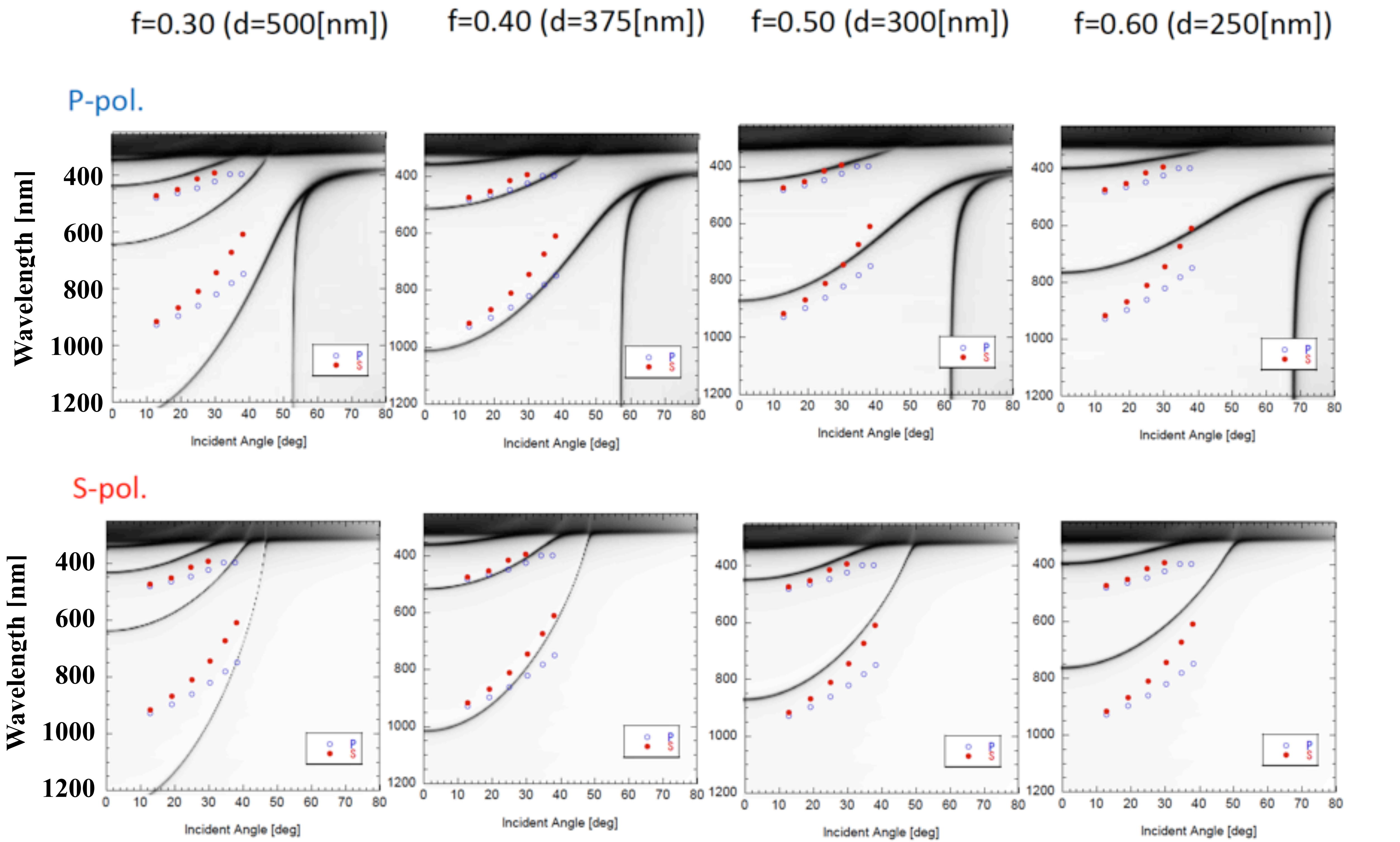


(a) Photograph of deposition chamber **(b) Photograph of control panel**

Vacuum deposition system used for experiment. The system has three independent power supplies for evaporation.

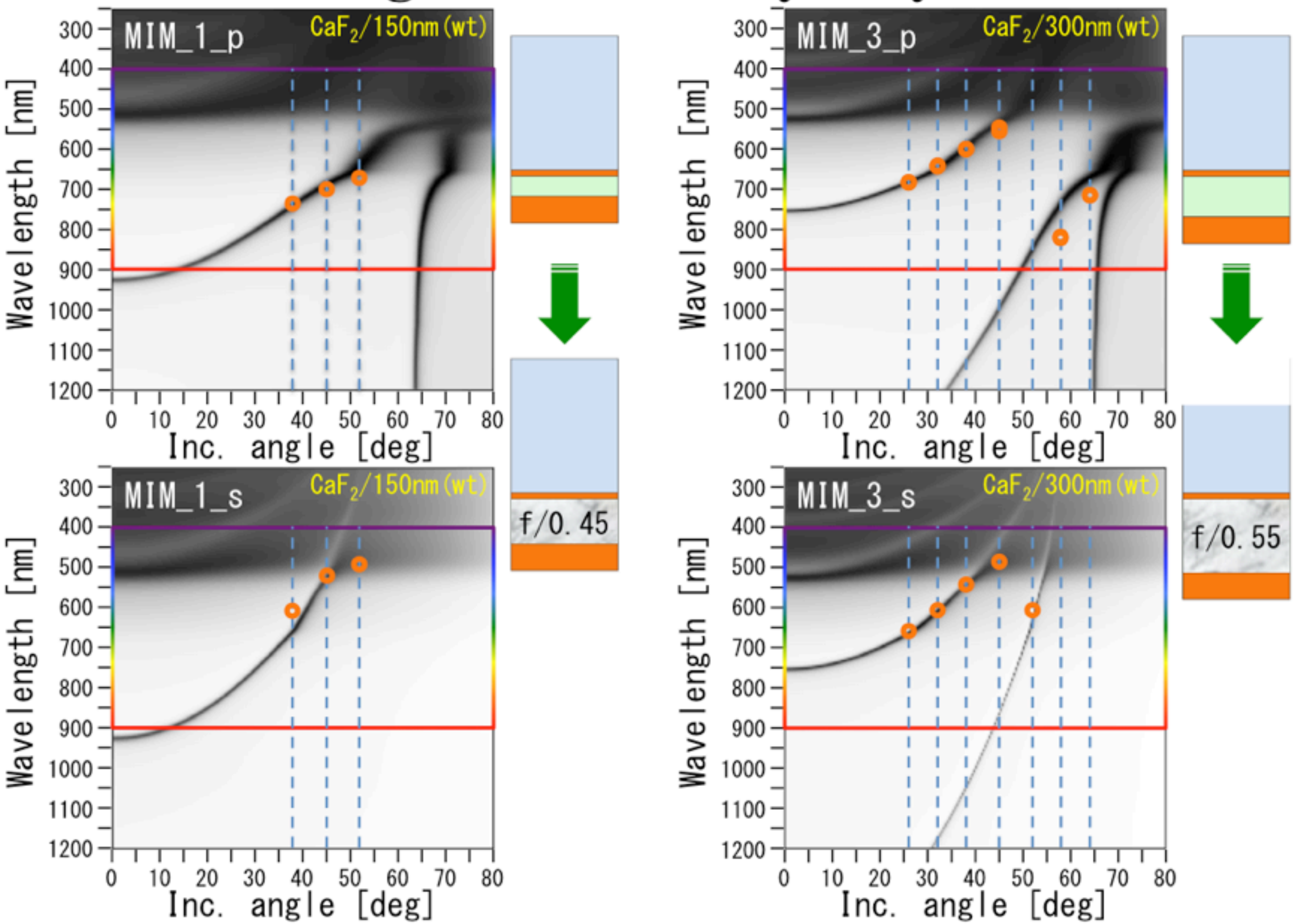


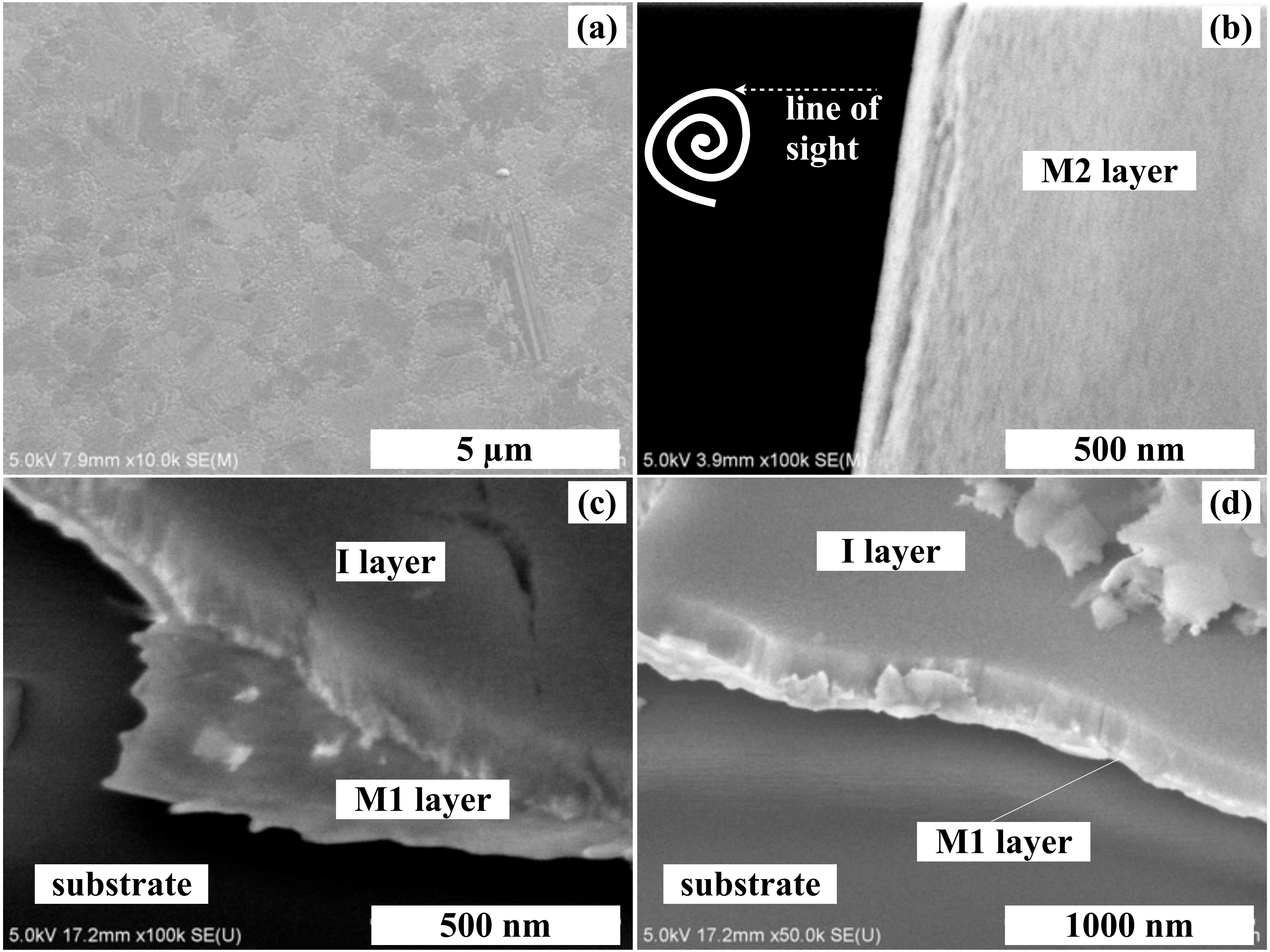
Setup for measurement of angular dependent spectral reflectance



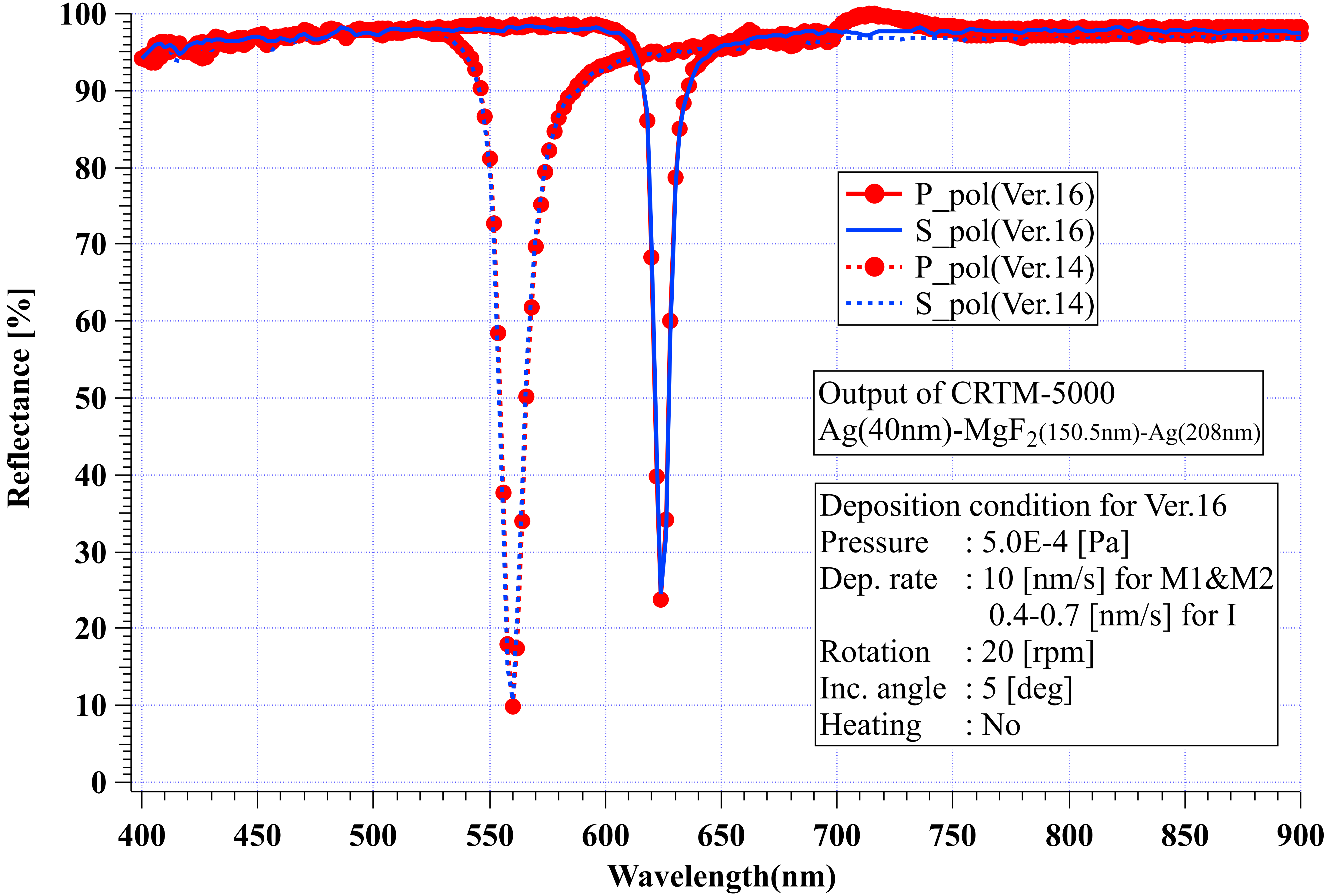
Experimental reflectance characteristics from sample prototypical MIM structure (Ver. 5, Glass slide/Ag (45 nm)/CaF_2(150 nm@*f* = 1)/Ag (200 nm)/Air). The red and blue circles correspond to P- and S-polarized light, respectively. The transfer matrix data agrees well between *f* = 0.4 and *f* = 0.5, where *f* denotes the filling factor of the CaF_2 film.

Resultant filling factor for I layer by T-matrix sim.



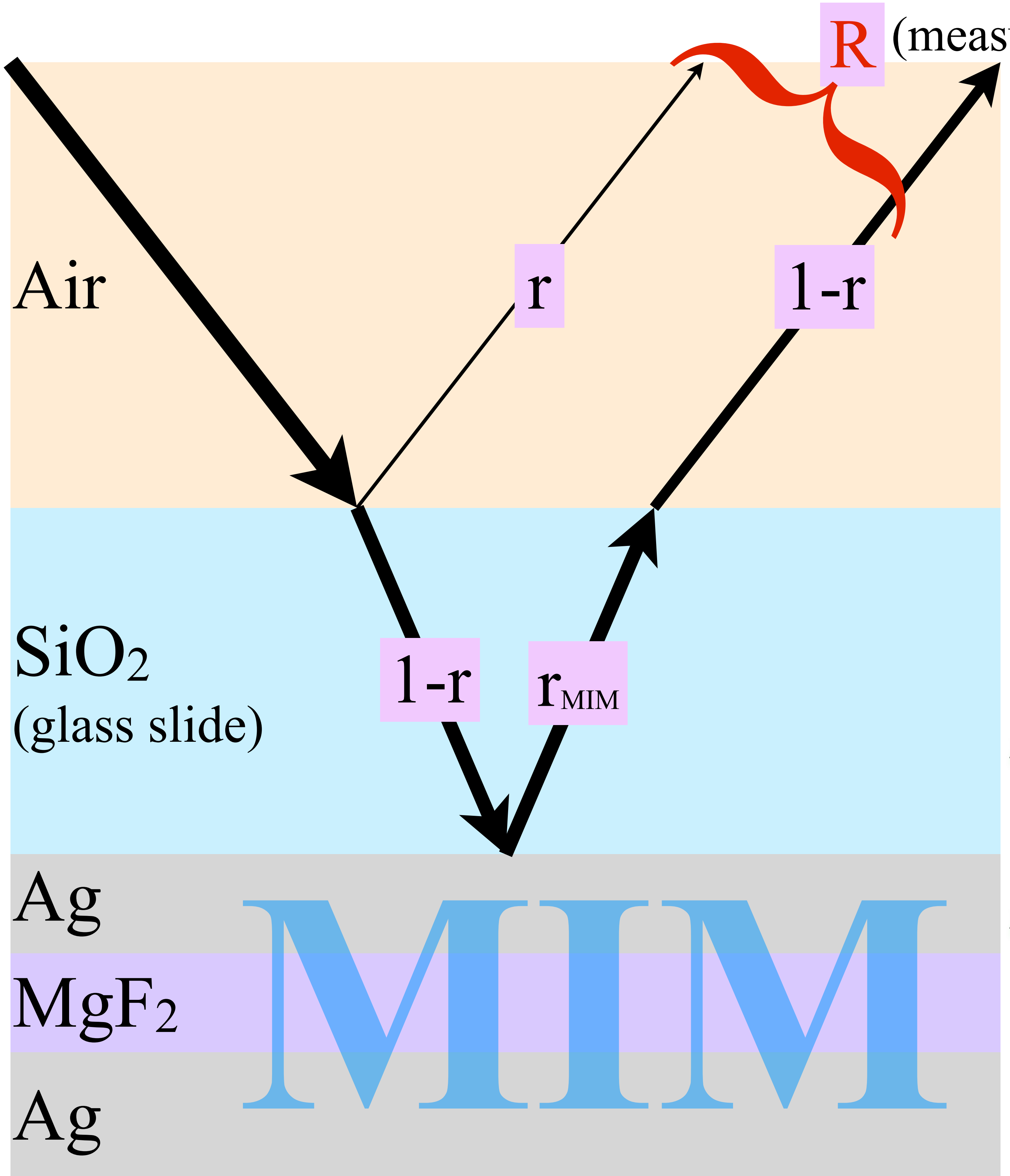


SEM images of MIM structure (Ver. 16). (a) The surface of the M2 (=Ag) layer, (b) oblique observation of the peeled M2 layer, and, (c), (d) oblique observation of the interfaces between the I (=MgF_2), M1 (=Ag), and substrate (= glass slide) layers.



Polarization-dependent spectral reflectance of prototypical MIM structures (Ag/MgF_2/Ag). P- and S-polarized diagnostic beams were incident on a sample at an angle of 5° from the target normal. The M layers of Ver. 14 and Ver. 16 were deposited at rates of 0.1 nm/s and 10 nm/s, respectively.

edge reflection and net reflectance of the MIM

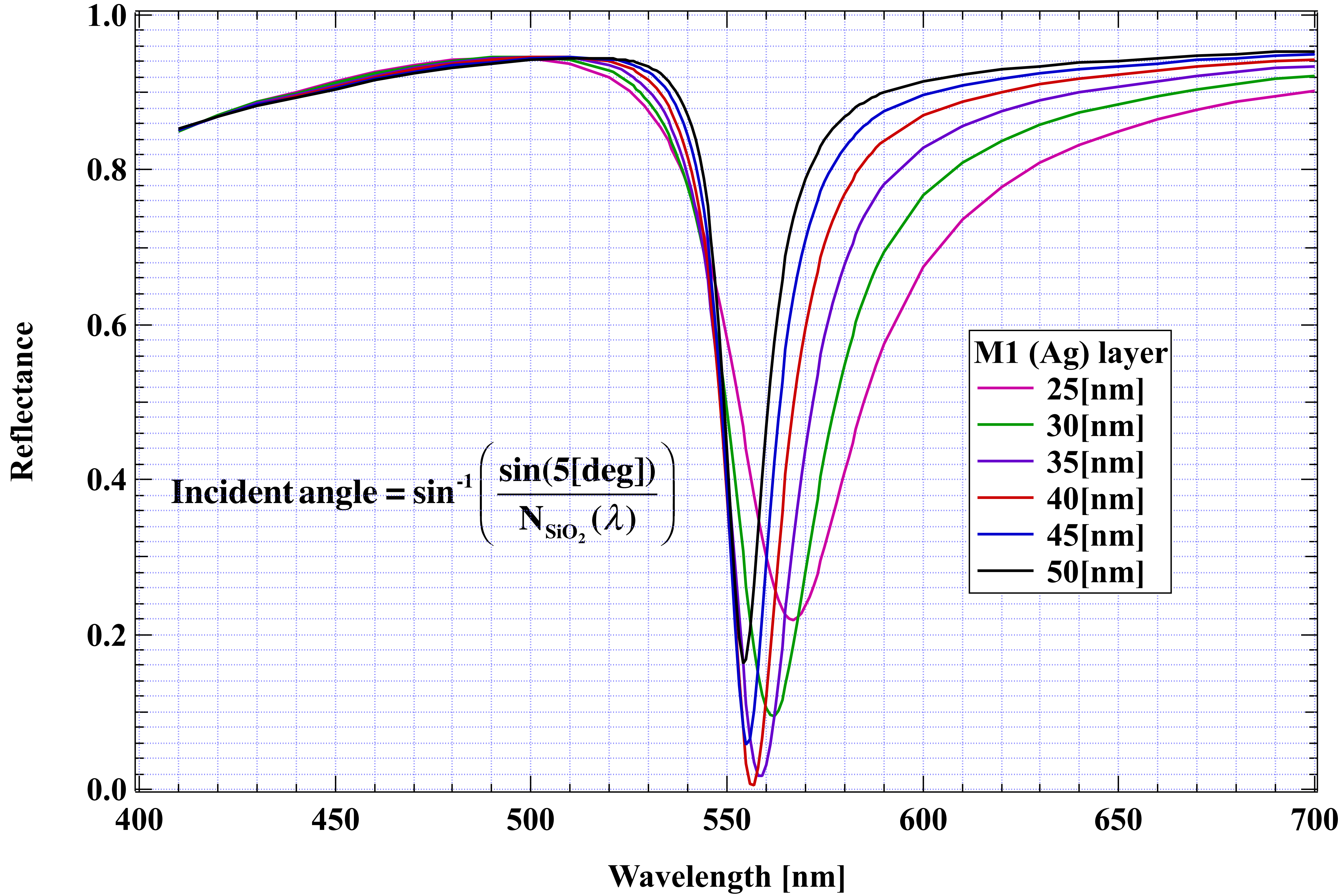


$$R \approx r + (1-r) \cdot r_{MIM} \cdot (1-r)$$

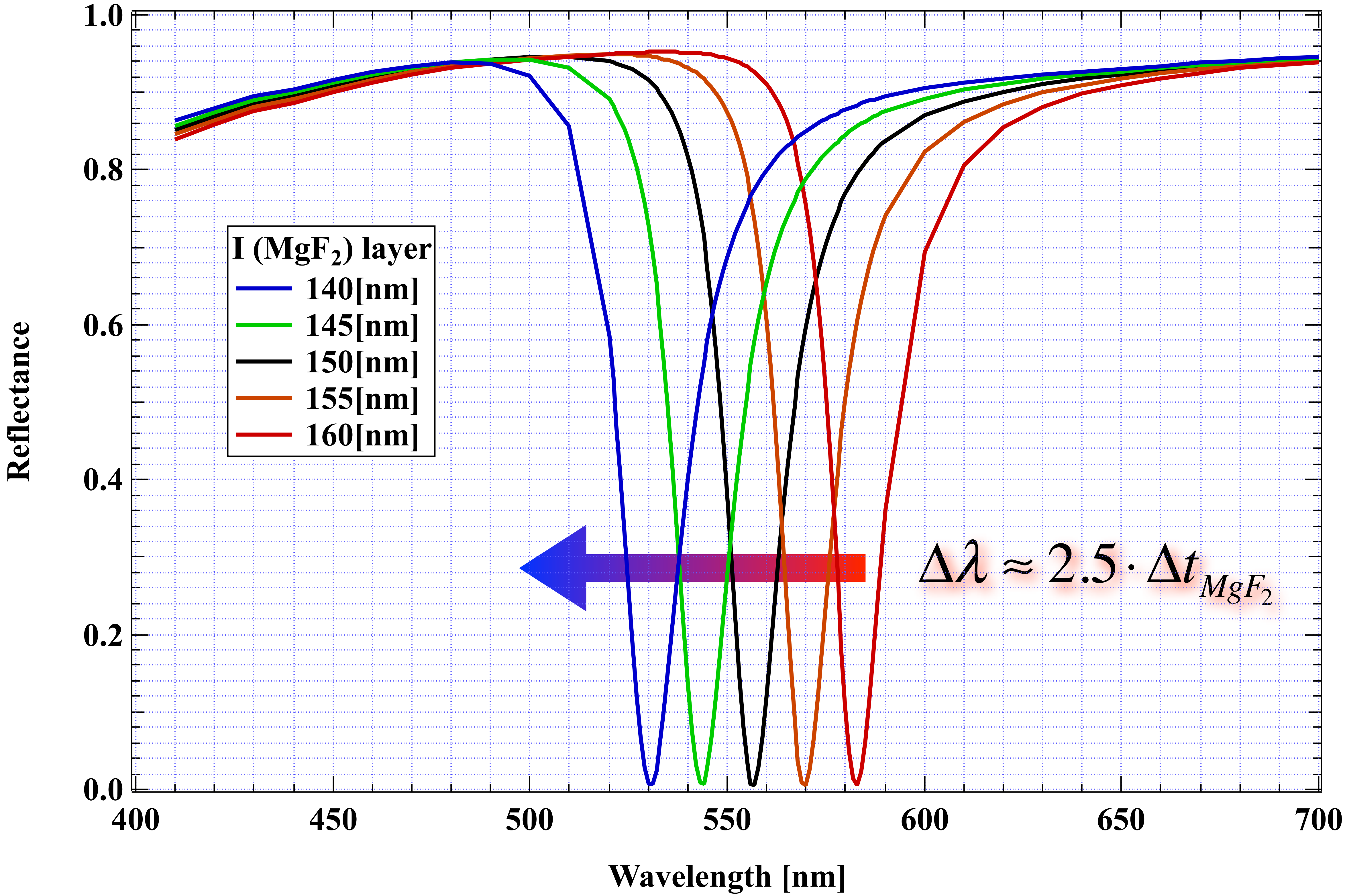
$$r_{MIM} = \frac{R-r}{(1-r)^2}$$

$$r_{MIM} = 0.998\,(R = 0.96,\, r = 0.04)$$

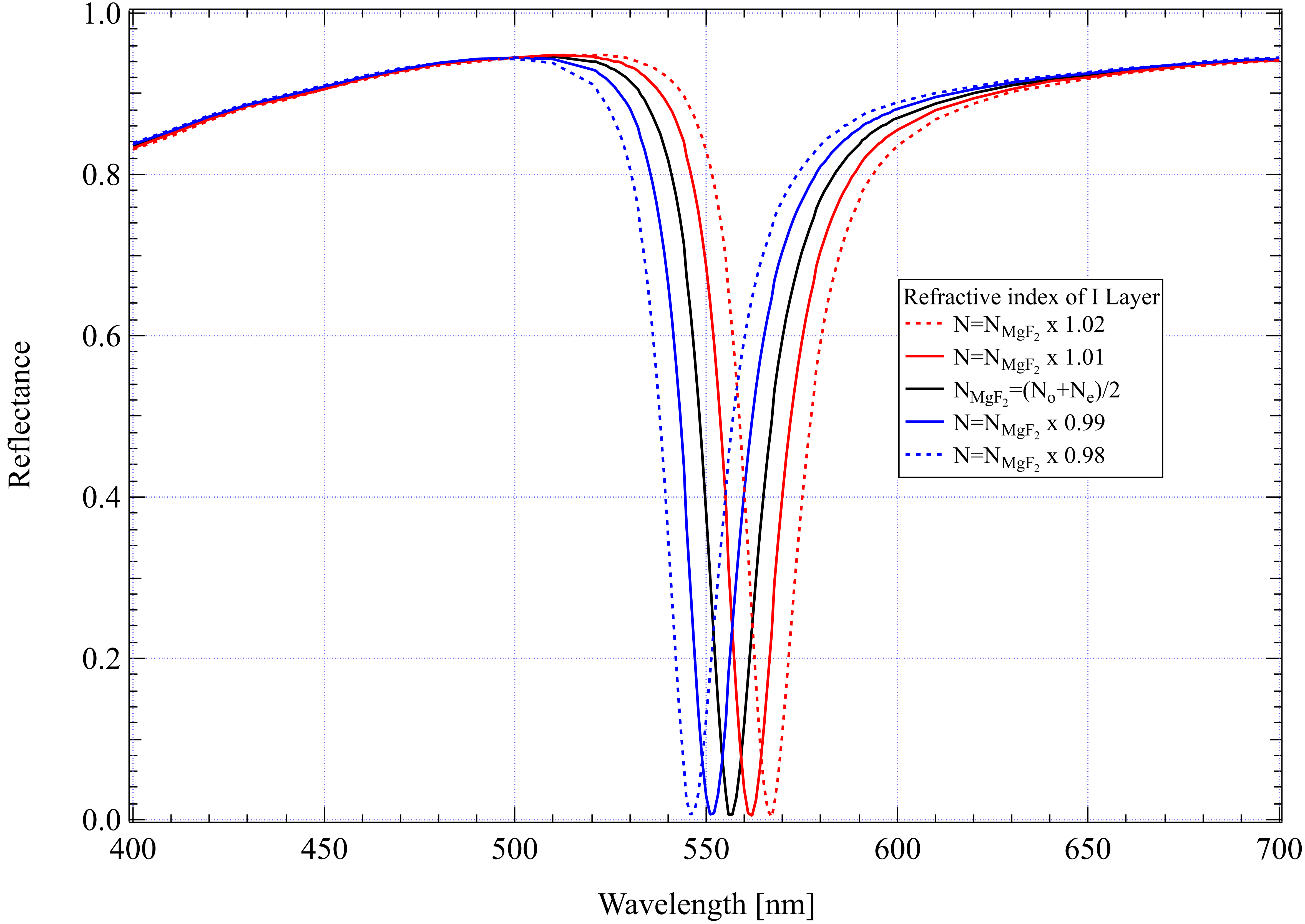
$$r_{MIM} = 0.065\,(R = 0.10,\, r = 0.04)$$



Spectral reflectance for MIM structure with configuration of M1 (Ag: 25 to 50 nm)/I (SiO_2: 150 nm)/M2 (Ag: 200 nm) without edge reflection of glass slide as calculated by FEM simulation. Reducing the thickness of the M1 layer causes a red shift of the absorption dip, and the depth is also affected.



Spectral reflectance for MIM structure with configuration of M1 (Ag: 40 nm)/I (SiO_2: 140 to 160 nm)/M2(Ag: 200 nm) without edge reflection of glass slide as calculated by FEM simulation. Reducing the thickness of the I layer causes a blue shift of the absorption dip, and the depth is not affected.



Affection of change in refractive index of I layer on absorption dip

まとめ

白色LED照明による可視光通信の実現に向けて，金属/誘電体/金属(MIM)構造を有するプラズモニックアクティブフィルタの開発に着手した.

厚み方向に非対称なMIM(厚いAg/MgF_2/薄いAg)構造をスライドガラス上に真空蒸着法により試作した結果，吸収ディップの半値全幅が7.5　nmのバンドカットフィルタ特性を得ることができた．今後はI層に適当な屈折率可変材料（EO材料など）を選定もしくは開発し，吸収ディップの波長方向の制御を可能としたい.

厚み方向に非対称なMIM構造について，その角度依存した分光反射特性をCOMSOL Multiphysics ＋ RF moduleにより実験と良く対応が付く形でシミュレーション解析することができた．今後はI層における高速な屈折率変化（EO効果）などの組み込みを進めてゆきたい.

謝　辞

本研究の遂行にあたり，(独)産業技術総合研究所 関西センター 村井健介 主任研究より研究協力をいただいております.

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