Supporting information:

Ultra-thin films with highly absorbent porous media fine-tunable for coloration and enhanced color purity

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Supporting Information 1: CIE color coordinate plot and color representation.

Basically, the color information is expressed by the tristimulus values, which comprises X, Y, and Z, conceptualized as amounts of three primary colors (i.e., red, green, and blue) in a tri-chromatic additive color model. To convert from reflectance to chromatic value, the tristimulus value is calculated by following equations:

$$X = \int M(\lambda)\bar{x}(\lambda)d\lambda$$
$$Y = \int M(\lambda)\bar{y}(\lambda)d\lambda$$
$$Z = \int M(\lambda)\bar{z}(\lambda)d\lambda$$

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ are the color matching functions, which are the numerical description of the chromatic response of the observer. In our calculation, the CIE 1931 standard observer function,[1] the most generally used, was employed as the color matching function (Figure S1). In the equation, reflectance, which is calculated or measured in our study, is multiplied by the color matching function as a spectral power distribution ($M(\lambda)$). In the CIE color coordinate, the chromaticity of a color was specified by the two derived parameters x and y, normalized values of all three tristimulus values by following equations:

$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$

From the calculated tristimulus values, RGB values is converted by the matrix as follows:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.41847 & -0.15866 & -0.082835 \\ -0.091169 & 0.25243 & 0.015708 \\ 0.00092090 & -0.0025498 & 0.17860 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

In this study, we calculated these above equations by using MATLAB. For the example of calculations, Figure S2 demonstrates (a) the spectral response of the tristimulus value and (b) the CIE plot with P_r 0%, 40%, 60%, and 75% at a Ge thickness of 20 nm.

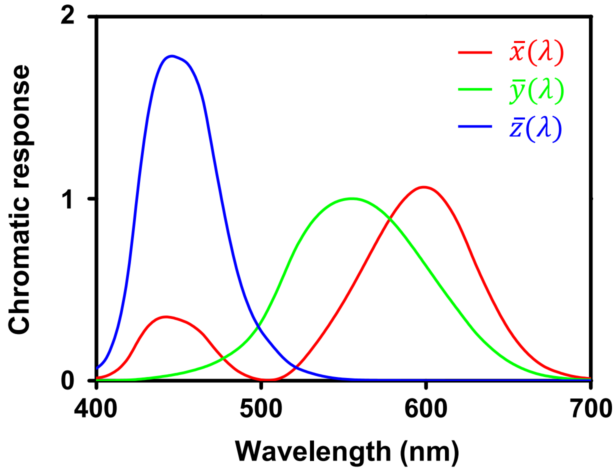


Figure S1. Chromatic response of the color matching functions from *CIE 1931 standard observer*[1]

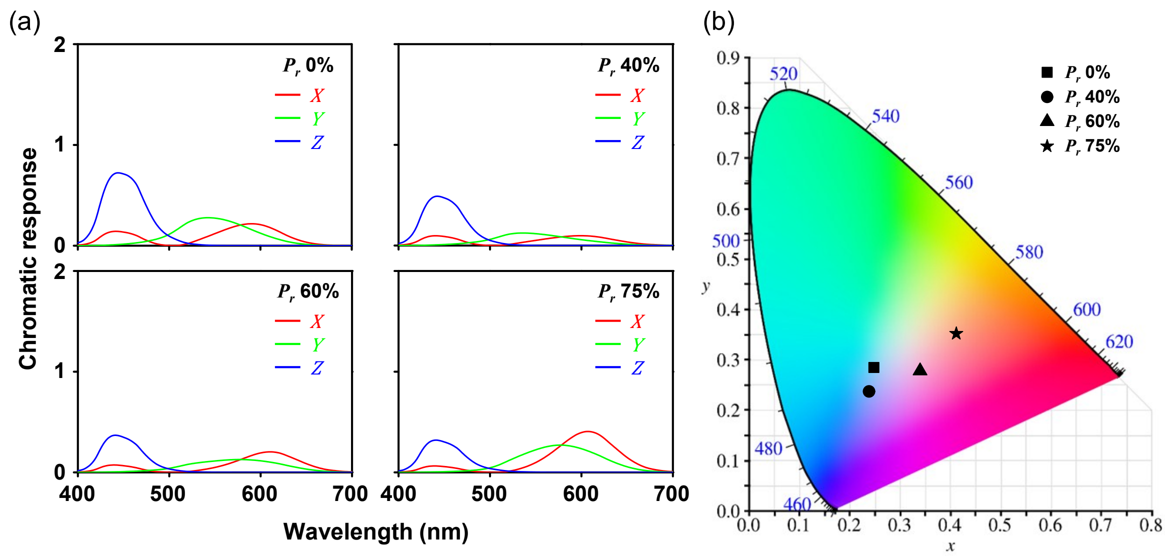


Figure S2. (a) Chromatic response of the tristimulus values and (b) the CIE plot with P_r 0%, 40%, 60% and 75% at a Ge thickness of 20 nm.

Reference

[S1] H. S. Fairman, M. H. Brill, and H. Hemmendinger, *Color Research & Application*, 1997, **22,** 11–23

Supporting Information 2: Resonance dip of reflectance at different wavelengths.

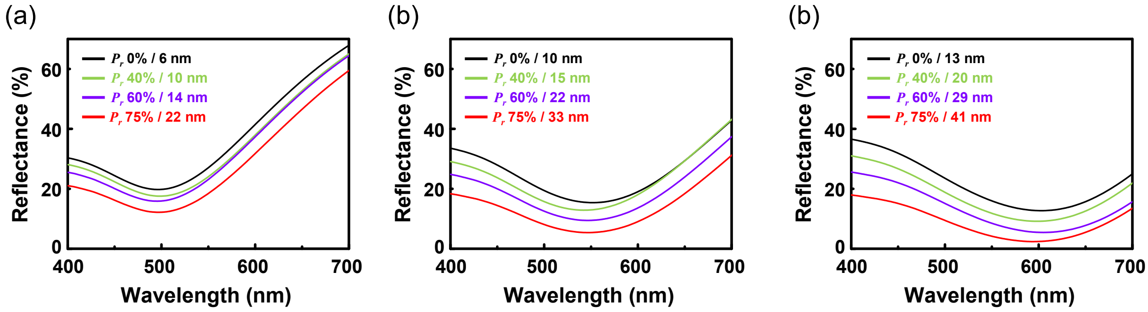


Figure S3. (a-c) Calculated reflectance spectra of P_r 0%, 40%, 60% and 75% with different Ge thicknesses enabling the minimum dip of reflectance at each wavelength of (a) 500 nm, (b) 550 nm and (c) 600 nm.

Supporting Information 3: Experimental setup and thin-film structures by OAD.

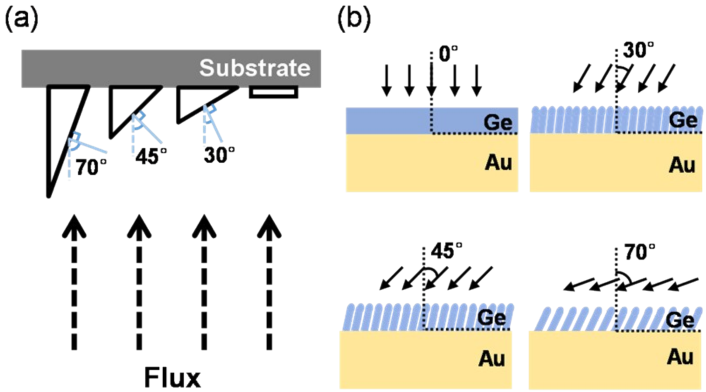


Figure S4 (a-b) Schematic illustrations of (a) experimental setup with inclined sample holders for the oblique angle deposition of Ge films and (b) deposited Ge films on Au substrate with oblique angles of 0˚, 30˚, 45˚ and 70˚

Supporting Information 4: Measurement of Ge thicknesses.

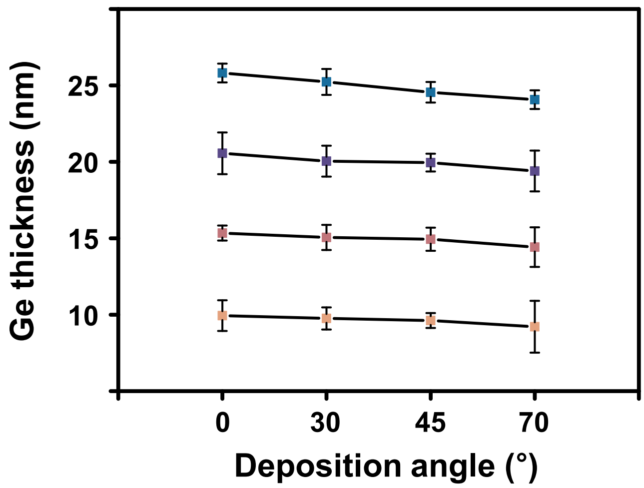
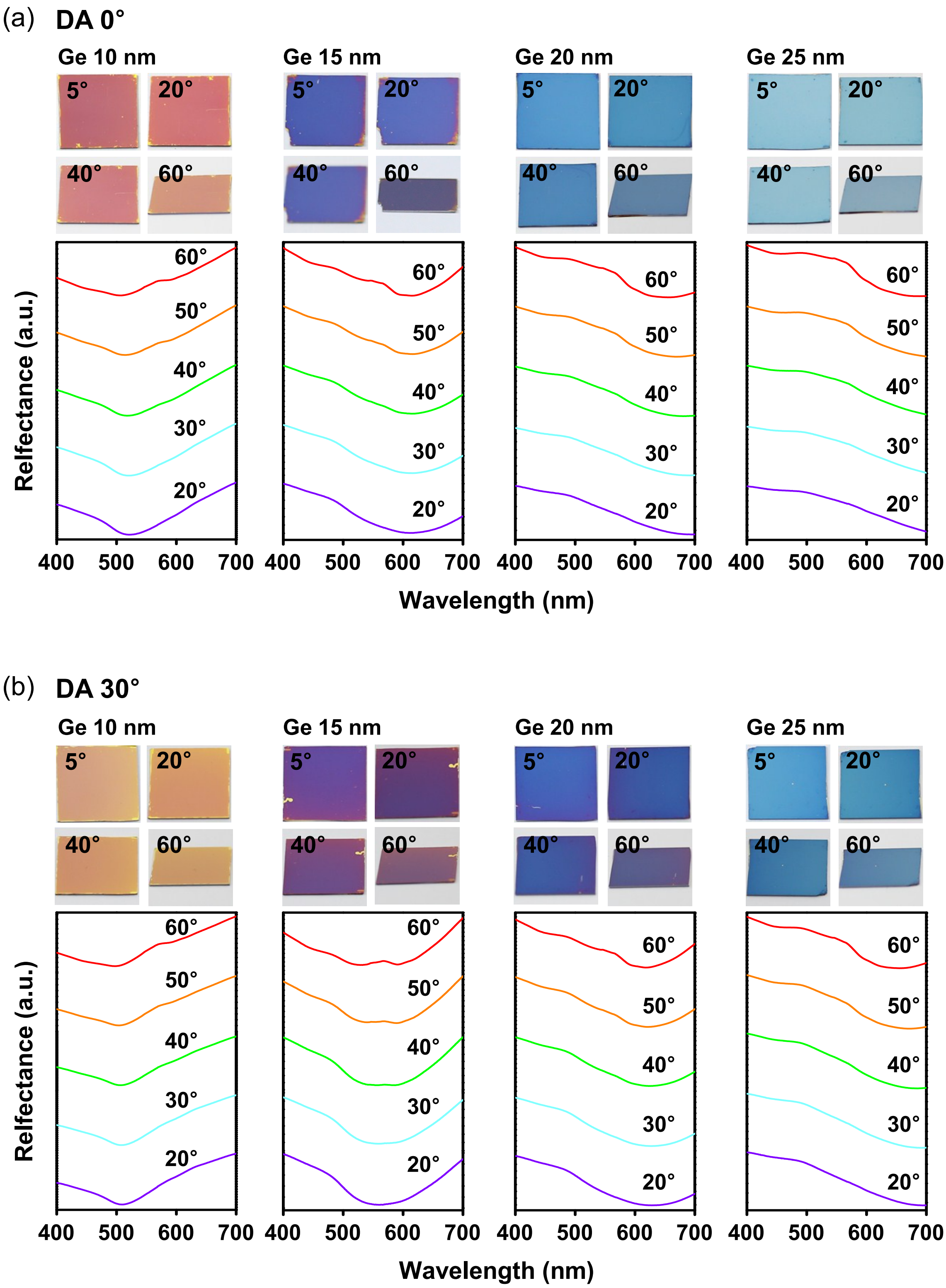


Figure S5. Measured Ge thickness in samples of different thicknesses (i.e. 10 nm, 15 nm, 20 nm and 25 nm) at each deposition angles (i.e. 0°, 30°, 45° and 70°) by atomic force microscopy.

Supporting Information 5: Angle dependency of the fabricated samples.



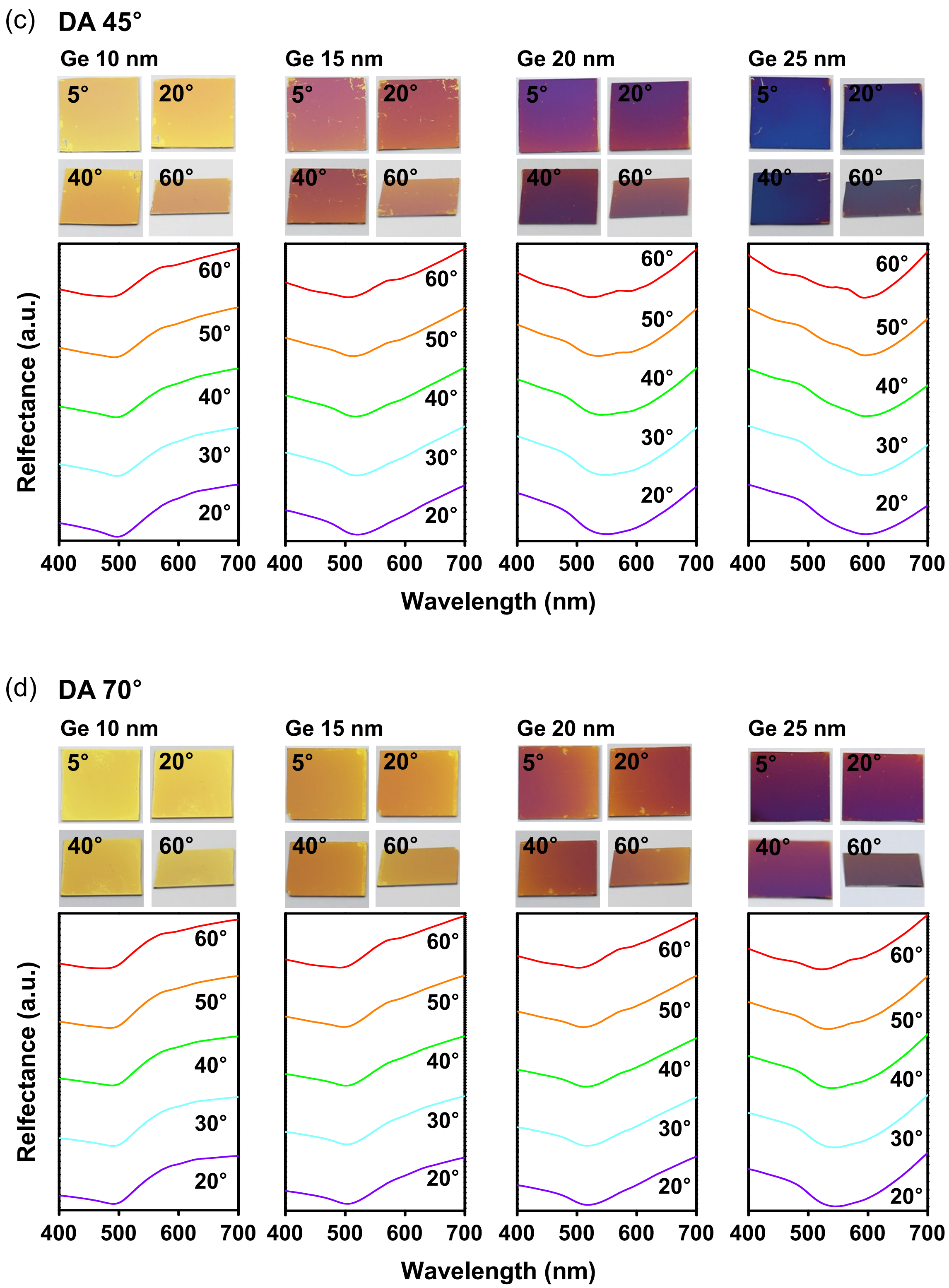


Figure S6. (a-d) Images with different angles of view from 5° to 60° and measured reflectance spectra at oblique angles from 20° to 60° of (a) DA 0º, (b) DA 30º, (c) DA 45º and (d) DA 70º with different thickness (i.e., 10 nm, 15 nm, 20 nm and 25 nm).

Supporting Information 6: Calculated reflectances for determining Au thickness.

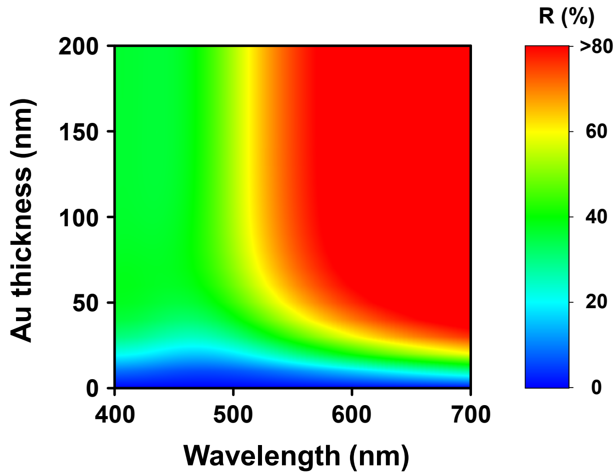


Figure S7. Contour plot of calculated reflectance variation as a function of Au thickness and of wavelength for determining sufficient optical thickness of Au.