

PDF issue: 2024-12-22

## Antireflection Substrates for Determining the Number of Layers of Few-Layer Hexagonal Boron Nitride Films and for Visualizing Organic Monolayers

Hattori, Yoshiaki Taniguchi, Takashi Watanabe, Kenji Kitamura, Masatoshi

(Citation) ACS Applied Nano Materials,6(23):21876-21886

(Issue Date) 2023-10-29

(Resource Type) journal article

(Version) Accepted Manuscript

(Rights) © 2023 The Authors.

(URL) https://hdl.handle.net/20.500.14094/0100486146



Supporting Information for:

## Antireflection Substrate for Determining the Number of Layers of Few-Layer Hexagonal Boron Nitride Films and for Visualizing Organic Monolayers.

Yoshiaki Hattori<sup>1\*</sup>, Takashi Taniguchi<sup>2</sup>, Kenji Watanabe<sup>3</sup>, and Masatoshi Kitamura<sup>1\*\*</sup>

<sup>1</sup> Department of Electrical and Electronic Engineering, Kobe University, 1-1, Rokkodai-cho, Nada, Kobe, 657-8501, Japan

<sup>2</sup> International Center for Materials Nanoarchitectonics, National Institute for Materials Science,
1-1 Namiki, Tsukuba 305-0044, Japan

<sup>3</sup> Research Center for Functional Materials, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

Corresponding author:

\*Email: hattori@eedept.kobe-u.ac.jp, \*\*Email: kitamura@eedept.kobe-u.ac.jp

## Note S1: Locus of a non-absorbing layer

The locus of a non-absorbing layer in the multilayer coating is a circular arc in the circle diagram. The arc is traced clockwise and increases with layer thickness. The half-wave layer traces out a complete circle. If a *q*-th non-absorbing layer is deposited on a (q - 1)-th layer, the size and position of the circle depend on the  $N_q$  and starting point of the arc, which corresponds to the termination of the locus of the previous layer, that is  $\rho_{q-1}(d_{q-1}) = \rho_q(0)$ . The locus of the  $\rho_q(d)$  is given by

$$\rho_{\mathbf{q}}(d) = \frac{\rho_q^T + \rho' \exp(-2i\delta_q)}{1 + \rho_1^T \rho' \exp(-2i\delta_q)},$$

where,  $\delta_q = 2\pi N_q d/\lambda$ ,  $\rho_q^T = (N_m - N_q)/(N_m + N_q)$ ,  $\rho' = (\rho_{q-1}(d_{q-1}) - \rho_q^T)/(1 - \rho_{q-1}(d_{q-1}) \rho_q^T)$ , respectively.<sup>16</sup> The center and radius of the arc are

$$\left(\frac{\rho_q^T (1-|\rho'|^2)}{1-|\rho'|^2 \rho_q^{T^2}}, 0\right)$$

and

$$\frac{|\rho'|(1-\rho_q^{T^2})}{1-|\rho'|^2\rho_q^{T^2}},$$

respectively. The center of the arc is on the real axis. In Sec. 4.4, the non-absorbing single layer on a metric base substrate is discussed for designing an AR coating with a layer of arbitrary materials on top, where it is important to consider the locus of the non-absorbing layer. In this case,  $\rho_{q-1}(d_{q-1})$  is  $\rho_{sub}$ . Figure S2 shows the loci of various non-absorbing layers with different refractive indices on the metric base substrate, indicating that the termination of the locus of a non-absorbing layer can be freely controlled in a wide range by adjusting the thickness and selecting the *R* of the base substrate.



Figure S1: The refractive index of  $SiO_2$  (a) and  $SiN_x$  (b) measured by the ellipsometer, respectively. The refractive index was obtained from dielectric dispersion with the Lorentz oscillator model.



**Figure S2:** Loci of various non-absorbing layers with different refractive indices on the metric base substrate.



Figure S3: (a) Monochromatic image for 1–4 L hBN on the AR substrate at  $\lambda = 530$  nm. (b–f) Tapping-AFM phase images corresponding to the red square in (a). (g–k) Height images corresponding to (b–f). (l–p) Profiles of the average height along the white solid bold lines in (g–k).



**Figure S4**: Calculated (a) reflection and (b) contrast spectra of AR substrates for NA = 0.7. The black and red lines indicate the Si/SiN<sub>x</sub> (62.0 nm) and Si/SiN<sub>x</sub> (50.0 nm)/ SiO<sub>2</sub> (25.0 nm) substrates, respectively. The contrast spectra is for 1L hBN on the AR substrate.