Thin films comprising heterogeneous metal-metaldielectric nanocolumns require different model approaches.

Ellipsometry Models for Nanohybrid Functional Columnar Thin Films

**Homogeneous Biaxial Layer**

F1-STFs can be described as single homogeneous biaxial layers with thickness d and complex functions $n_{eff}$, are individually determined.

- Euler angles $\Theta$, $\Phi$ of rotation matrix $A$.
- Internal angles $\beta$ of projection matrix $U$.

$$\varepsilon = AU$$

where:

- $A$ is the rotational matrix (Euler angle rotation)
- $U$ is the projection matrix (if triclinic or monoclinic)

**Traditional Anisotropic Bruggeman EMA (TAB-EMA)**

Slanted columns are represented by spatially aligned, anisotropic inclusions of three major effective polarizabilities $P_{ijkl}$, along principal axes $i$, $j$, $k$.

$$\sum_{i,j,k} f_i n_i - \sum_{i,j} f_{ij} n_{ij} = 0$$

**Rigorous AB-EMA**

A more rigorous approach considers the depolarization dyadic to be a function of the inclusions' shape $U_{ij}$ and effective permittivity tensor ($\sigma$-electrodynamic approach).

$$D_j = \frac{1}{4\pi} \int \frac{U_{ij}}{\rho} d\theta d\phi$$

where:

- $U_{ij}$ is the rotational dyadic tensor
- $\rho$ is the electron density
- $\theta$ is the polar angle
- $\phi$ is the azimuthal angle

**Results and Applications**

**Conformal Dielectric ALD Coating**

- Conformal ALD coating on a columnar thin film.
- Optical modeling with ellipsometry.
- Depolarization dyadic to be a function of the inclusions' shape $U_{ij}$.

**Conformal Metal ALD Coating**

- Conformal ALD coating on a columnar thin film.
- Optical modeling with ellipsometry.
- Depolarization dyadic to be a function of the inclusions' shape $U_{ij}$.

**In-situ ALD Growth Monitoring**

- Growth monitoring with ellipsometry.
- Depolarization dyadic to be a function of the inclusions' shape $U_{ij}$.

**Metal - Dielectric**

- Optical modeling with ellipsometry.
- Depolarization dyadic to be a function of the inclusions' shape $U_{ij}$.

**Metal - Metal**

- Optical modeling with ellipsometry.
- Depolarization dyadic to be a function of the inclusions' shape $U_{ij}$.

- Set of depolarization factors for each constituent required.

- AB-EMA approach yields excellent fraction estimates for thin films with heterogeneous nanocolumns.