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Characterization of metallic nano-particles via surface wave scattering: A. Theoretical framework and formulation

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Abstract

Characterization of nano-size particles and structures are crucial for successful application of self-assembly processes that lead to bottom-up machining and manufacturing concepts. Conventional light-based approaches cannot be used for these purposes, mainly because the particle and structure sizes are much smaller than the wavelength of visible light. To overcome this problem, we are in the process of developing a diagnostic tool based on surface-wave scattering. In this paper, we outline the governing equations required to describe the scattering of the electromagnetic field by a particle located near a film. The formulation given here is for a general case; a special application of this work to surface waves can be obtained by considering the fields propagating at near grazing angles. This work constitutes the theoretical frame work needed for the characterization of nano-particles on or above a thin metallic film via scattered surface waves, which is outlined in Part B (JQSRT (2004)).
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Nomenclature

a	diameter of the spherical metallic particle
$A_n^{(n',m)}, B_n^{(n',m)}$	vector translation coefficients
$\boldsymbol{B}$	scattering response matrix
d	distance between the film surface and center of the particle
$\boldsymbol{E}_{\text{inc}}$	incident electromagnetic radiation vector
$\boldsymbol{E}_{\text{sca}}$	scattered electromagnetic radiation vector
h	thickness of metallic film
$h_n^{(1)}(k_2r_2)$	spherical Hankel functions of the second kind
$J_n(k_2r_2)$	spherical Bessel functions of the first kind
k	wave number
m	complex refractive index
n	real part of refractive index (m)
$\boldsymbol{M}, \boldsymbol{N}$	vector spherical harmonics
$P_n^m(\cos\theta_j)$	associated Legendre polynomials
r	distance between sensor and particle
R_{ij}	Fresnel reflection coefficient from medium i to medium j
$\boldsymbol{S}$	scattering matrix
S_{ij}	scattering matrix elements of the metallic particle
S_l	scattering amplitudes ($l = 1, 2, 3$ and 4)
T_{ij}	Fresnel transmission coefficient from medium i to medium j
α	incident angle from medium i to medium j
θ_s	scattering angle
μ	permeability
λ	wavelength of incident radiation

1. Introduction

Effective use of the self-assembly of nano-size particles (particles as small as 1–10 nm in size) is likely to have a significant impact on the bottom-up nano-scale machining and manufacturing processes. For the success of this concept, it is important to have strict control of the process itself. Conventional light-based approaches cannot be used for diagnosis of self-assembly, mainly because the particle and structure sizes involved are much smaller than the wavelength of typical laser lights. Even though electron-microscopy (SEM, TEM) or atomic-force microscopy (AFM) are used widely to observe the nano-scale structures, they are intrusive and do not lend themselves for real-time, on-line monitoring approaches.

Recently, we have proposed a novel method that can be used for characterization of nano-size particles and structures on or near metallic surfaces [1]. This approach, called the elliptically polarized surface-wave scattering (EPSWS) method, is based on the detection of metallic particles on or near a metallic surface that tunnel the evanescent waves and then scatter their energy and eventually can be combined with real-time visualization approaches. The possibility of detecting