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Optics and Lasers in Engineering 43 (2005) 885–894
OPTICS and LASERS in ENGINEERING

Bulge deformation measurement and elastic modulus analysis of nanoporous alumina membrane using time sequence speckle pattern interferometry

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Abstract

Nanoporous alumina membranes containing parallel regular pores of uniform size and normal to substrate surface were fabricated by anodically oxidizing high purity aluminum foils in acid solutions. The continuous out-of-plane displacement and current load of the porous membranes were obtained through bulge test combining time sequence speckle pattern interferometry (TSSPI) observation system. Then the deformation of whole field under different loads was deduced through point-to-point scan analysis and the elastic modulus was calculated through an analytical model. Measurement of mechanical properties indicates unusual mechanical behavior of these anodic alumina films compared with bulk alumina materials or dense alumina films. This method is useful and convenient for mechanical test on membranes with such structure and bring further understanding on connecting of micro–meso structure and mechanical properties.

Keywords: Nanoporous alumina membrane; Bulge test; TSSPI; Elastic modulus

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0143-8166/$ - see front matter
doi:10.1016/j.optlaseng.2004.09.006

1. Introduction

The anodic aluminum oxide (AAO) membrane has a packed array of columnar hexagonal cells with central, cylindrical, uniform size holes ranging from 4 to 200 nm in diameter. There has been increasing interest in anodic alumina membrane due to its unique structure and self-organization, as well as potentially wide applications in filtering and separating membrane [1,2]. Furthermore, it provides a convenient route for fabricating 1D nanostructures with various size and shape when using alumina membranes as templates [3,4]. However, their mechanical properties have been scarcely reported. In this paper, the continuous out-of-plane displacement and current load of the porous films were obtained through bulge test combining time sequence speckle pattern interferometry (TSSPI) observation system and the elastic modulus of the porous alumina membranes was calculated through an analytical model. This observation may shed light on application of these membranes with nanopore arrays and bring further understanding on connecting of micro–meso structure and mechanical properties.

2. Principle

When laser beam illuminates to a deforming diffuse object surface and a still reference surface, the two reflective lights will interfere and a sequence of time-dependent interference speckle pattern will occur. Thus, the continuous deformation of the object surface can be obtained by analyzing the time-dependent interference speckle pattern in time-domain. To meet this kind of applications, an optical technique called time sequence speckle pattern interferometry (TSSPI) has been introduced and got rapid development in recent years [5–7]. In this paper, TSSPI is employed to measure the continuous deformation in bulge test of anodic alumina membrane and the results has been used to calculate its elastic modulus combined with current load.

The intensity of a time-dependent interference speckle pattern can be described as follows:

$$I(x,y,t) = I_0(x,y) + I_{\mathrm{m}}(x,y)\cos\phi(x,y,t), \tag{1}$$

where $I_0(x,y)$ and $I_{\mathrm{m}}(x,y)$ are average intensity and modulation factor respectively, $\phi(x,y,t)$ is a temporal phase sequence caused by the object deformation. In practice, $I_0(x,y)$ and $I_{\mathrm{m}}(x,y)$ are also functions of time, but their changes is quite slow compared with that of the phase function during the deformation of the film. Therefore, the effect of the time factor on them can be omitted.

In the case of monotonic growth of the deformation, the phase function in Eq. (1) can be obtained from

$$\begin{aligned}\Delta\phi(x,y,t_{\mathrm{i}}) &= M(x,y,t_{\mathrm{i}})\pi + \Delta\phi_1(x,y,t_{\mathrm{i}}) + \Delta\phi_2(x,y,t_{\mathrm{i}})\\ &= [M(x,y,t_{\mathrm{i}}) + \Delta m_1(x,y,t_{\mathrm{i}}) + \Delta m_2(x,y,t_{\mathrm{i}})]\pi\\ &= [M(x,y,t_{\mathrm{i}}) + \Delta m(x,y,t_{\mathrm{i}})]\pi,\end{aligned} \tag{2}$$