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An inverse method for determining the interaction force between the probe and sample using scanning near-field optical microscopy

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Abstract

This study proposes a means for calculating the interaction force during the scanning process using a scanning near-field optical microscope (SNOM) probe. The determination of the interaction force in the scanning system is regarded as an inverse vibration problem. The conjugate gradient method is applied to treat the inverse problem using available displacement measurements. The results show that the conjugate gradient method is less sensitive to measurement errors and prior information on the functional form of quality was not required. Furthermore, the initial guesses for the interaction force can be arbitrarily chosen for the iteration process.

Keywords: Scanning near-field optical microscope; Inverse vibration problem; Conjugate gradient method

1. Introduction

Scanning near-field optical microscopy (SNOM) has become an increasingly used technique for the optical investigation of materials in a nanometer scale, since it has demonstrated to overcome Abbe's diffraction limit of conventional far-field optical microscopy in the optical near-field range [1–5]. The optical fiber probe plays an important role in SNOM. When the probe scans the sample surface, it allows simultaneous measurement of the topography image and optical transmission of the surface at high resolution [6–9].

According to the direction of vibration of the oscillator, the SNOM has three vibration modes, which include one axial and two lateral directions. Each mode results in the optical fiber probe to move in different direction and to induce the nonlinear interaction forces between the optical fiber probe and the sample. Generally, the interaction forces between the optical fiber probe and the sample surface are difficult to measure

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directly, but they can influence the sensitivity of the probe. Therefore, the high resolution of the SNOM optical topography image benefits the investigation of the interaction forces.

In this Letter, the axial probe–sample interaction force was considered as unknown. The governing equation and the corresponding initial conditions form the inverse vibration problem. Many methods of solving the inverse vibration problem have been developed, for instance, the sequential estimation method [10], the conjugated gradient method [11] and the Levenberg–Marquardt method [12].

In this Letter the conjugated gradient method was used to estimate the axial interaction force. The advantage of the conjugated gradient method is that an iterative regularization is implicitly built in the computational procedure. The method can quickly obtain to the target's function. It is very powerful and has been used to solve the function estimation problem by many researchers [13–16].

2. Analysis

The schematic diagram of the SNOM apparatus is shown in Fig. 1. An optical fiber probe cantilevered at one end is key element of the SNOM. When the SNOM scans the sample's surface, the axial interaction force between the optical fiber probe and the sample surface is induced. The axial interaction force depends on the rigidity of the probe and the surface, is also dependent on time and can be modeled as the axial force, $F(t)$, on the probe. When the interaction force is unknown, the system can be considered as an inverse vibration problem.

In this Letter, the conjugate gradient method, a function estimation approach, was adopted to deal with the inverse problem. The calculation process of the method includes the following problems: the direct problem, the sensitivity problem and the adjoint problem, which are discussed as follows.

2.1. Direct problem

For simplifying the problem, the optical fiber probe is assumed to have a uniform circular cross section and the coating of the optical fiber was not taken into account in this Letter.

The probe experiences axial vibrations during contact with the probe-sample. The axial vibration motion of a cantilever was a partial differential equation and its axial displacement u was dependent on time t and the spatial coordinate x [17]. The linear differential equation of motion and the corresponding boundary

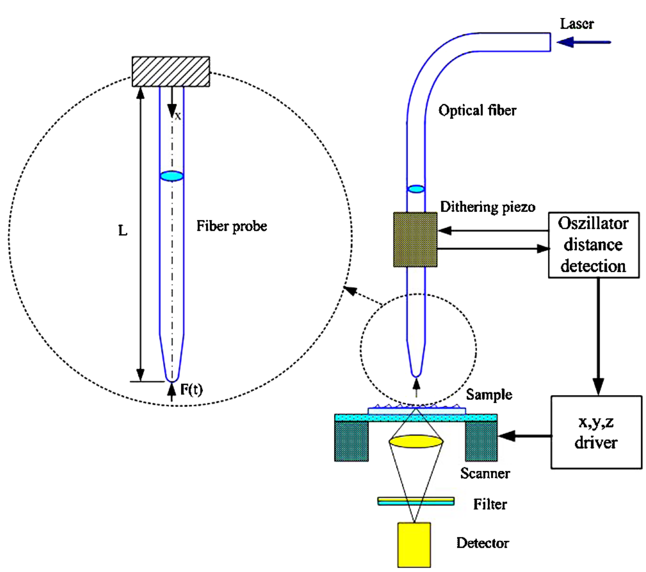

Fig. 1. Schematic diagram of the SNOM apparatus. The axial interaction force between the optical fiber probe and the sample surface is modeled as the axial force, $F(t)$, on the probe.