Frequency-modulated impulse response photothermal detection through optical reflectance. 1: Theory

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The 3-D theory of impulse response photothermal detection in opaque (i.e., photothermally saturated) solids through the dependence of the surface temperature optical reflectance on the mathematical equivalent of an optical impulse (the Green's function) is presented. The theory is extended to include the effects of the finite spatial extent of the photothermal laser source. Explicit expressions for the time-dependent temperature field have been obtained in the experimentally important cases of semi-infinite solids and solids of finite thickness in contact with thermally insulating or conducting backings.

I. Introduction

The optical generation of thermal wave phenomena in materials has in recent years provided a powerful method of microscopy for the nondestructive evaluation of integrated circuits and other device materials. The unique advantage posed by thermal wave microscopy is its ability to perform nondestructive thermal depth profiling of extremely shallow surface layers in materials. The short-range critically damped character of thermal waves in solid media and the decrease in thermal penetration depth with increased modulation frequency are responsible for these high resolution depth profiling capabilities. The use of focused lasers to generate highly localized heating at the surface of a material has enabled the resolution of micron sized features.

Recently, a very powerful methodology, in which thermal wave phenomena could be detected noninvasively via optically induced thermoelastic deformations[1,2] and optical reflectivity changes[3] at the sample surface, has emerged. Detection was achieved via a pump–probe configuration in which a highly focused heating beam was absorbed at the sample surface, inducing a thermal bump due to the thermoelastic effect, with simultaneous changes in sample reflectance due to variations of the surface temperature. Detection of thermal waves was achieved both thermoelastically, in which the thermal surface deformations produced deflections of the probe beam, or by changes in the sample's surface reflectance with temperature, which produced variations in the integrated intensity of the probe beam. Because of the availability of fast photodiodes and quad-cell detectors, the very wide bandwidth of the technique is, therefore, capable of resolving thermal images limited by optical rather than thermal diffraction.

Previous work which has used this technique for thermal imaging has been carried out exclusively in the frequency domain, in which the modulation frequency of the irradiation source was varied on a point-by-point basis, and the reflectivity or thermoelastic response signals were detected narrowband using a lock-in amplifier. Recently, Eesley *et al.*[4–6] have introduced pulsed laser picosecond transient thermoreflectance (TTR) as a fast sensitive technique capable of measuring thin film thermal diffusivity and time-resolved thermal transport processes in metal samples. This technique is also based on the principle of optical reflectivity changes at the sample surface as a result of local laser heating. Time-domain pulsed-laser schemes have further been used with other photothermal wave imaging systems such as the flash radiometric technique developed by Leung and Tam,[7] which is based on the noncontact detection of transient infrared (blackbody) radiation from a sample heated by a short optical pulse. These schemes, however successful with materials tolerant to steep temperature excursions, cannot be used with delicate materials, such as semiconductor substrates and devices, without severe restrictions in the exciting laser beam parameters, as the high pump irradiances tend to alter (anneal or otherwise damage) the surfaces and device structures

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(54) **LIGHT PROFILE MICROSCOPY APPARATUS AND METHOD**

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(57) **ABSTRACT**

An apparatus and method allowing an optimized illumination in a light profile microscope by excitation of a sample with an elliptically collimated beam. The beam, which is typically supplied by a laser is collimated with unequal beam waist radii (and Rayleigh ranges) along major and minor axes orthogonal to a propagation direction, and approximates a plane sheet of illumination. The plane sheet of illumination is aligned with a thinnest width dimension thereof along the optic axis of the microscope objective, and with a center thereof at the object plane of the objective. Excitation light in a test sample is thereby confined to within a narrow thickness of the object plane of the objective lens, which minimizes out-of focus light in the image. The major axis width of the plane illumination sheet is typically a factor of ten or more greater than the minimum width, allowing a large area of the test sample to be illuminated and imaged. This excitation arrangement optically emulates the operation of micro-toming a thin cross section of a material for analysis, and provides optimum resolution and field in a light profile microscope.

15 Claims, 4 Drawing Sheets