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A semiconducting thermooptic material for potential application to super-resolution optical data storage

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Abstract

To find its practical use in ultrahigh density optical data storage, superresolution (SR) technique needs a material that can render a high SR capability at no cost of durability against repeated read/write. Thermoelectric materials are proposed as candidates capable of yielding solid state SR effects in the absence of phase changes that are detrimental to durability. As a prototype material, PbTe is selected due to a large thermoelectric Seebeck coefficient and a high stability of a crystalline single phase state up to its melting temperature of 924 °C. A preliminary study of $Pb_{51}Te_{49}$ thin films was carried out with the following findings: Firstly, under exposure to pulsed light, completely reversible changes in transmittance take place regardless of power. Secondly, light transmittance grows with increasing laser power and this is not due to melting except at relatively high powers. By way of optical calculations using the measured reflectance and transmittance values combined with thermal calculations, a temperature variation of effective optical constants (n, k) was also estimated to find that both of them decrease with increasing temperature.

Keywords: Optical data storage; Superresolution; Thermoelectric; Thermooptic; PbTe

1. Introduction

A so-called superresolution (SR) technique is considered to have a high potential for an ultrahigh density optical data storage beyond optical diffraction limit without sacrificing a critical advantage of the present optical disk technology, i.e. removability. Nevertheless, the SR technique has progressed little beyond an infant stage due to unsuccessful material development. As for a prime material requirement, SR capability[1], the most promising results have been obtained mostly with materials yielding large changes in optical properties due to phase transitions of either melting or decomposition. Each of these materials, however, has led to limited readout cycles as in the case of 'premastered optical disk by superresolution (PSR)' utilizing the melting transition of a Chalcogenide GeSbTe alloy [1] or limited applicability to WORM type disks as in the case of Super-RENS disks utilizing the oxide decomposition of either AgO [2,3] or PtO [4,5]. For superresolution technique to find its use in ROM and rewritable disks in particular, therefore, development of a new class of SR materials that can maintain a high SR capability during a long cyclic readout and/or writing operation appears to be called for. To fulfill such a requirement, materials are not supposed to owe their SR capability to phase changes, especially of the sorts accompanying structural modifications. In this report, we propose a new class of SR materials of such a kind and present preliminary experimental results using a prototype material.

In pursuit of new materials, a primary guideline was set out, prompted by existing experimental findings made with SR optical disks suggesting that GeSbTe alloys yield some degrees of solid state SR effects in the absence of phase

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[1] SR capability, as used here, refers to the ability to yield a large Carrier to Noise Ratio (CNR) during readout of information marks spaced with a period less than a conventional resolution limit (λ/2NA, where λ and NA are respectively wavelength and numerical aperture of the lens).

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changes [6]. While no mechanistic description of the effects is available, we postulate that they may have much to do with the thermoelectric nature of the GeSbTe alloys, which are narrow band gap degenerate semiconductors: When a focused laser beam with a Gaussian intensity profile irradiates a thermoelectric thin film, a strong optical absorption may take place, providing that the photon energy of the incident beam exceeds the band gap of the material. This, in turn, leads to a spatial temperature distribution with a steep gradient, promoted by a low thermal conductivity that is required for a good thermoelectric material in general. As a result, electric fields are set up in proportion to temperature gradients that would interact with those of the incident light. And the magnitudes of the electric fields and the degrees of the resulting interactions would become greater with thermoelectric Seebeck coefficient. Without further speculations, it may suffice to state for our present purpose that light transmitting through a thermoelectric thin film may be eventually rendered to have a modified intensity profile due to such interactions, possibly prompting SR effects.

Along this line of postulation, a prototype material was first in search among semiconducting materials with large thermoelectric Seebeck coefficients. Another requirement was imposed that a material be able to maintain a highly stable single crystalline phase state up to its melting temperature significantly higher than those of GeSbTe alloys. The prototype material of our choice turned out to be PbTe as it has a large Seebeck coefficient of about 200 μV/K at room temperature [7] and maintains an intermetallic crystalline single phase state until melting occurs at 924 °C [8].

2. Experiments and results

PbTe thin films were prepared by co-sputtering of Pb and Te targets in a RF magnetron sputter unit. RF sputter power to each target was controlled so as to yield about the same deposition rate for each element and the resulting films were found to have the composition of Pb-51at.% Te-49at.% from RBS analysis. As for test samples, each was made to have a three-layer stack consisting of a single layer of PbTe film sandwiched with ZnS–SiO_2 protective layers either on a glass substrate or on a C-coated Cu grid substrate. Structural analyses were carried out by use of XRD and TEM with three-layer samples having ZnS–SiO_2 layers of 10 nm thick each. For optical characterization, each ZnS–SiO_2 layer of three-layer samples was made to have a thickness of $\lambda/2n$ (151 nm for λ=633 nm) and the samples were tested using a laboratory-built two-beam static tester equipped with an objective lens of 0.6 NA and a 685 nm LD source for pulsed heating together with a 633 nm CW laser source for signal detection, as schematically shown in Fig. 1. By use of an additional CW laser source for probing instead of a single pulsed source for both heating and probing, one can avoid difficulties in postprocessing of signal data such as calibration with respect to laser power and leaving out transient effects inherent in a pulsed laser beam, etc. As for the 685 nm heating laser beam, the focal diameter is around 0.78 μm at the $1/e$ times the peak value of the Gaussian intensity profile, leading to the power density of about 2 mW/μm^2 at 1 mW laser power for instance.

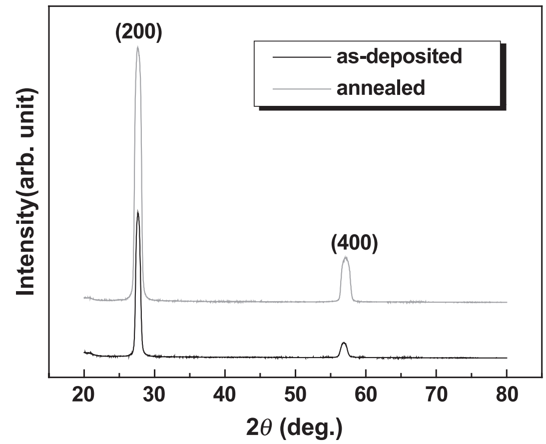

Fig. 2. XRD spectra of $Pb_{51}Te_{49}$ films in both as-deposited and annealed (at 250 °C for 5 min) states.

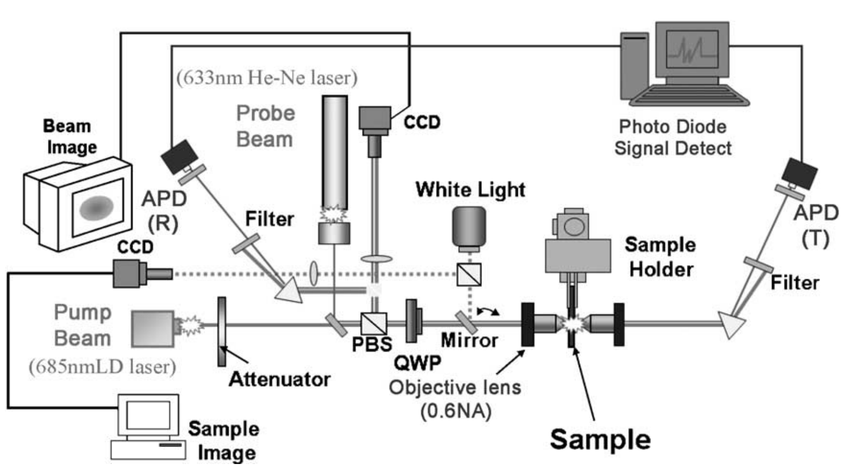

Fig. 1. A schematic of two-beam static tester for real time reflectance/transmittance measurement.