EXPLORING THE SPATIAL RESOLUTION OF THE PHOTOTHERMAL BEAM DEFLECTION TECHNIQUE IN THE INFRARED REGION

W. Seidel, H. Foerstendorf, Forschungszentrum Rossendorf, 01314 Dresden, Germany
F. Glotin, J.M. Ortega, R. Prazeres, LURE, 91898 Orsay Cedex, France

Abstract

In photothermal beam deflection (PTBD) spectroscopy generating and detection of thermal waves occur generally in the sub-millimeter length scale. Therefore, PTBD provides spatial information about the surface of the sample and permits imaging and/or microspectrometry. Recent results of PTBD experiments are presented with a high spatial resolution which is near the diffraction limit of the infrared pump beam (CLIO-FEL).

INTRODUCTION

The PTBD technique is based on the theory of photothermal spectroscopy which describes the conversion of absorbed energy of a light beam incident on a sample into heat by nonradiative de-excitation processes [1]. The distribution of this induced, exponentially decaying, thermal field is given by the solution of the heat equation with a source term of a Gaussian beam [2]. In typical PTBD experiments the magnitude of the signal is proportional to the slope of the induced displacement of the sample surface. Additionally, it can be shown that there is a direct proportionality between the observed signal and the absorption coefficient of the material under investigation [2]. Therefore, a direct access to absorption spectra is provided [3]. The detection limit is expected to be extremely low since absorptions as low as 10^{-6} to 10^{-8} have been measured in the visible region by this method [4].

In typical PTBD experiments a solid sample is irradiated by a modulated beam of monochromatic light produced by a tunable infrared laser and a probe beam (*e.g.* a HeNe laser) which is reflected from the sample (Fig. 1). Depending on the modulated intensity of the pump beam the photoinduced displacement of the probe beam changes periodically and thus a different reflection angle is observed by the use of a high resolution position detector. The resulting beam deflection signals are shown in Fig. 2.

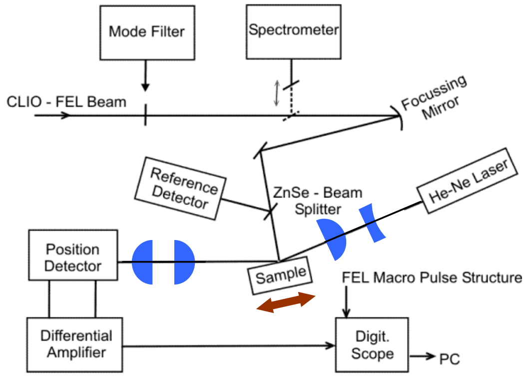

Figure 1: Layout of the PTBD experiment setup used at CLIO for microspectrometry.

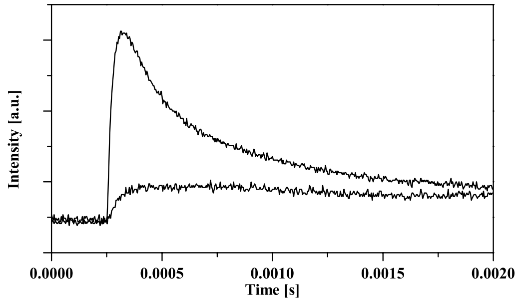

Figure 2: Time-resolved beam deflection signals of a strong absorbing (upper trace) and a nearly transparent sample (lower trace).

We investigated O^+-implanted and untreated regions of germanium substrates serving as model surfaces. The different areas of the surfaces can be distinguished by optical absorption (*i.e.* the amplitude of the deflection signal) at $\lambda = 11.6$ µm of the germaniumoxide produced during the implantation process (Fig. 3).

RESULTS

Simple Border Range

We investigated the border range of O^+-implanted and untreated regions of a germanium substrate serving as a model surface. The different areas of the surface can be distinguished by optical absorption (*i.e.* the amplitude of

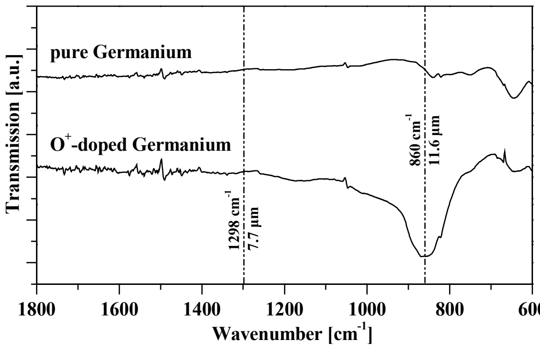

Figure 3: FT-IR transmission spectra of a Ge-substrate of O^+-implanted and untreated regions.

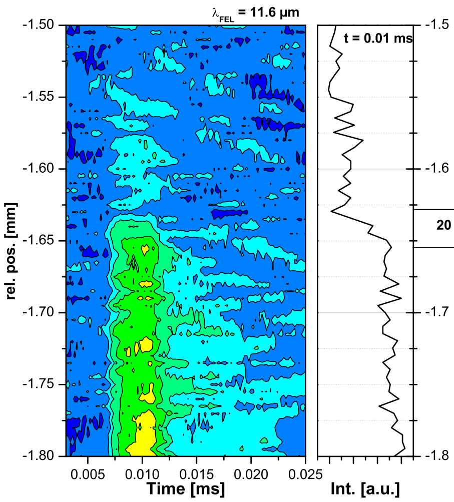

Figure 4: Mapping plot of the set of time curves of the deflection signal at distinct sample positions and the extracted absorption profile of the border range between O^+-doped and pure germanium (extracted at t = 10 µs and at λ = 11.6 µm).

the deflection signal) at λ = 11.6 µm of the germaniumoxide produced during the implantation process (Fig. 3). From the set of time curves (Fig. 2) recorded at distinct positions of the surface of the sample profiles can be obtained reflecting the distribution of the implanted oxygen in the substrate as it is shown in Fig. 4.

The transition between an O^+-doped and an untreated region of the substrate was investigated. The HeNe laser probe beam was focused in front of the surface of the sample to about 15 µm. This leads to an enhancement of the spatial resolution up to about 20 µm as it can be seen around 1.65 mm rel. pos. (Fig. 4, right panel).

Revcovery of More Complex Structures

In the next series of our experiments we investigated a sample showing a distinct pattern of implanted regions which was achieved by a special stainless steal mask in front of the substrate during the implantation process. The dimensions of the mask are given in Fig. 5A. Additionally, the implanted regions are indicated as grey stripes throughout Figs. 5 B-D.

The profiles presented in Fig. 5B clearly reproduce the structure of the implanted regions generated by the mask.

In Fig. 5C an enlarged range of five thin implanted regions were detected at high resolution of positioning (step width: 2 µm). Again, the recovery of the pattern of implantation is of excellent quality. For demonstration that the deflection signal is solely caused by optical absorption the same sample area was recorded at a wavelength of 7.7 µm where no absorption occurs (Fig. 3). This is demonstrated in Fig. 5D.

It is noteworthy, that all profiles shown in this work were obtained with only one macropulse for each sample position. A significantly higher signal-to-noise ratio can be expected when the deflection curves are averaged over several FEL pulses. This will probably facilitate the reproduction of more complex structures by PTBD-FEL microspectrometry.

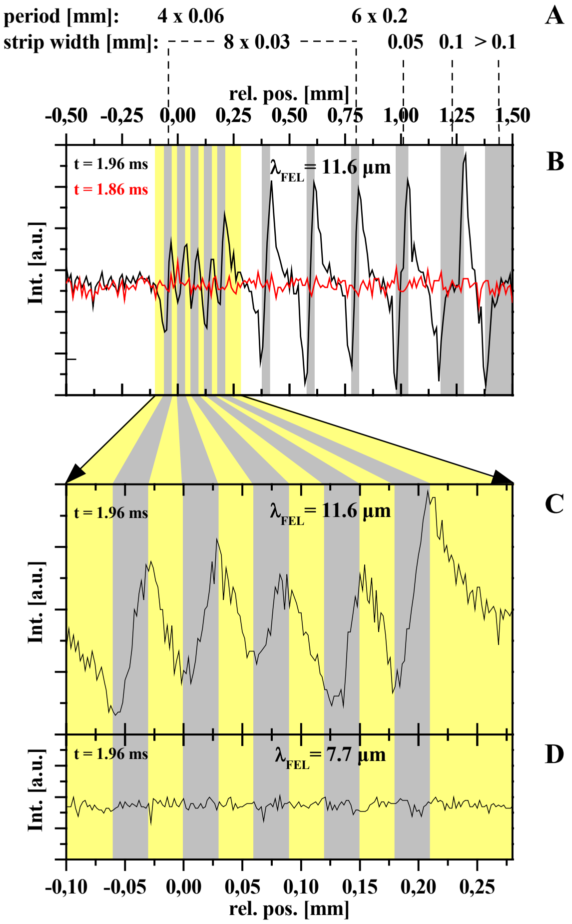

Figure 5: Dimensions of the implantation pattern for the preparation of the Ge-substrate with O^+-ions (A). Extracted absorption profiles (B-D): Profiles (step width: 10 µm) of the whole implanted structure at different times after the FEL pulse (black line: time of max. deflection, red line: time before deflection occur) (B). Profiles (step width: 2 µm) of five thin lines at different wavelengths (C-D). 11.6 µm: max. absorption (C), 7.7 µm: no absorption (see Fig. 3) (D).

References

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