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Application of the nitroanisole as an infrared detector used in middle infrared interferometer

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Abstract

We propose the application of nitroanisole as a detector for middle infrared (mid-IR) interferometry or holography. The present experiment utilizes the liquid form of nitroanisole, which has a thermal lens effect, i.e. a temperature dependent refractive index. Since the nitroanisole absorbs IR radiation as heat, it is possible to estimate the IR intensity distribution on the nitroanisole from the diffraction pattern made by visible laser light that is transmitted through the nitroanisole. In this study, the time resolution and the diffraction efficiency of the nitroanisole was measured under various conditions. The experimental results show that the nitroanisole has a time resolution as high as that of a standard video camera, as well as a high diffraction efficiency and the spatial resolution equivalent to that of a conventional IR camera. Furthermore, we confirmed that the phase shift in mid-IR region can be estimated by analyzing the change in the visible diffraction pattern.

Keywords: Nitroanisole; Interferometer; Infrared detectors

1. Introduction

In recent years, many devices that can detect infrared (IR) radiation have been invented. Detectors that contain such devices as pyroelectric devices and HgCdTe diodes have been used in applications of IR laser interferometry [1–3], non-destructive inspection [4], medical diagnosis [5], etc. In particular, interferometry is very effective for phase measurement, and some studies on plasma measurement [1,2] or digital holography [6] using a CO_2 laser of wavelength 10.6 μm have been reported. However, some of the devices used in these techniques have various restrictions, for instance, that they must be used in a cryogenic system, or that the detectors must be arranged in a matrix in order to obtain a two-dimensional image in a single trial. We propose the use of nitroanisole as a much simpler device with purpose of detecting mid-IR radiation. The nitroanisole exhibits a thermal lens effect [7–9], in which the refractive index is dependent upon temperature. This effect results in phase modulation on visible light, in direct response to intensity of the incident IR radiation, which is absorbed as heat. In the case of IR laser interferometry, interference fringe patterns that are created by the IR laser on the nitroanisole are observed as the refractive index distribution, hence the nitroanisole functions as a phase grating for visible light. It is, therefore, conceivable to estimate the IR intensity distribution on the nitroanisole by analyzing the diffraction pattern made by a visible laser, which is transmitted through the nitroanisole. Also, since a two-dimensional device using the nitroanisole does not require matrix structure, it is expected that the measurement system must have high spatial resolution, equivalent to that of existing IR cameras.

The purpose of this paper is to investigate the time resolution and the diffraction efficiency of the nitroanisole for a detector in mid-IR spectrum range. In addition, we attempt to estimate the phase shift in mid-IR region based on the change of visible diffraction patterns.

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2. Characteristics of the nitroanisole

The nitroanisole has three positions of *o*-, *m*-, and *p*-nitroanisole. We propose to use *o*-nitroanisole which is a colorless or slightly yellow liquid with a boiling point of 277 °C, a melting point of 9.4 °C, and molecular weight of 153.14, as a mid-IR detector. The *o*-nitroanisole in our experiment has significant thermal lens effect, which means the refractive index for visible light is dependent on temperature. We tested that the refractive index of *o*-nitroanisole varied according to temperature at a rate of -1.1×10^{-3} [1/K] as shown in Fig. 1. In addition we confirmed that it has an absorption band in mid-IR region by infrared absorption spectroscopy and that it hardly absorbs visible light. Therefore when the nitroanisole is irradiated with the IR radiation, its temperature rises, causing its refractive index to decreases.

3. Experiments and results

3.1. Time resolution

The experimental setup for measuring the time resolution and the diffraction efficiency is shown in Fig. 2. The nitroanisole was sandwiched between the glass substrate and ZnSe, an IR transmitting material. The thickness between the two substrates was adjusted by a film spacer and determined to be about 100 μm. Linearly polarized light from a continuous wave (c.w.) CO_2 laser of 10.6 μm wavelength was divided into two beams of roughly equal intensity by a beam splitter and the two beams were superimposed onto the nitroanisole cell at the appropriate angle to create the interference fringe pattern on the nitroanisole, which was illuminated by a He–Ne laser of 632.8 nm wavelength. Accordingly, since a refractive index distribution with periodic variation according to the interference fringe pattern was constructed on the nitroanisole, we were able to observe the diffracted He–Ne laser light. We measured the time variation of the intensity of the first-order diffraction He–Ne laser which was induced by the interference of the CO_2 laser with a photo detector. A mechanical shutter unit was located outside of the CO_2 laser resonator in order to avoid any possible sudden change to the CO_2 laser power caused by Q-switched oscillation. One graph of the measured time variation of diffracted He–Ne light intensity is shown in Fig. 3. Irradiation time of the CO_2 laser was about 500 ms. The diffraction efficiency, the rise time, and the fall time were defined respectively as the intensity ratio of the first-order diffraction light to that of zero-order, the time to rise from the initial state to 90% of static level, and the time of decrease to 10% of static level. In order to understand the dependencies of the diffraction efficiencies on both spatial frequency of interference fringe and laser power density, both the angle between two CO_2 laser beams and the laser output power density were changed.

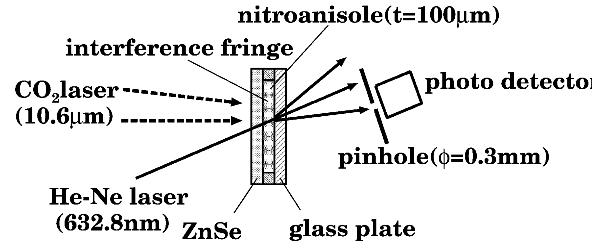

Fig. 2. Experimental setup for measuring the time resolution and the diffraction efficiency.

Fig. 4 shows the dependency of the CO_2 laser output power density on the time resolution of the nitroanisole. The spatial frequency of the interference fringe made by the CO_2 laser on the nitroanisole was 2 lp/mm. This result indicates that the rise time becomes shorter and the fall time becomes longer in response to an increase in the CO_2 laser output power density. When the CO_2 laser output power density was increased from 0.5 to 3.0 W/cm^2, the rise time changed from 45 to 36 ms and the fall time changed from 14 to 24 ms. We surmised that the reason why the rise time became shorter is that the time to reach

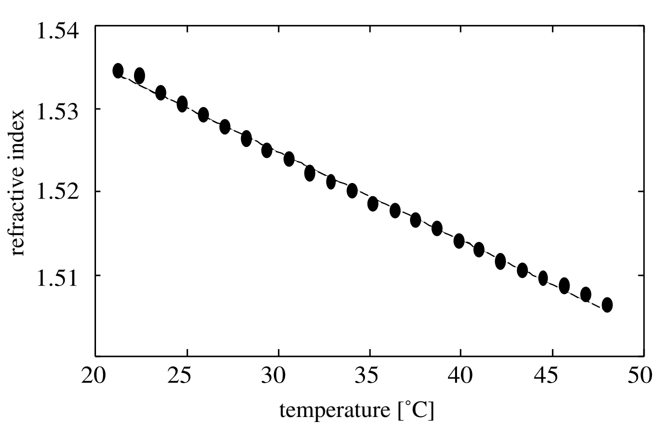

Fig. 1. Temperature dependence of the refractive index of the nitroanisole.

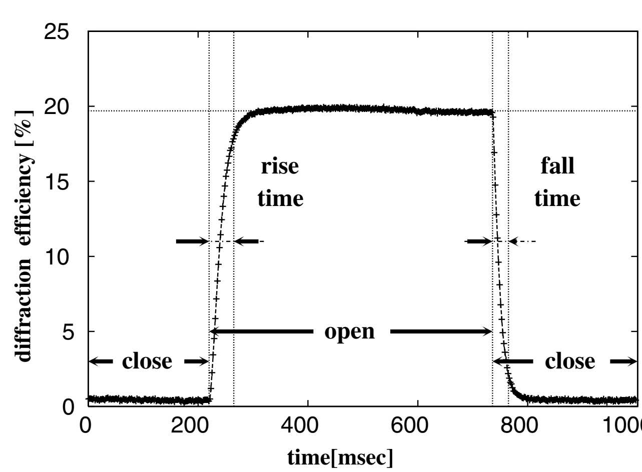

Fig. 3. Time variation of the first-order diffraction of He–Ne laser light intensity.