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Index and gain gratings in Nd-YVO4 - Applications to speckle vibrometry and photoacoustic detection

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Abstract. We perform wave mixing and dynamic holography by exploiting gain saturation in diode pumped laser media like Nd-YVO4. Such crystals offer the possibility of performing adaptive gain interferometers with a sub ms response time, typically between 100- 200µs. This temporal response is of great interest for applications such as speckle interferometry and acousto-optic detection for tissue imaging in biophotonics. In this work we operate in new conditions of high sensitivity with a linear response due to a refractive index contribution in the gain media. It originates from the wavelength mismatch of about 0.1 nm between the incident Nd-YAG probe laser and laser transition in diode pumped Nd-YVO4 amplifier. This permits the recording of two types of volume holograms respectively a gain and a phase volume holograms. It is the index grating which provides a linear response to incident low phase modulation at frequencies higher than 10 kHz. Experimental results confirm this behavior for adaptive interferometry and speckle vibrometry. In addition, the fast response makes the two wave mixing interaction in Nd-YVO4 very interesting for the optical detection of large bandwith photoacoustic waves excited by a pulsed ns Q-Switch laser at 532 nm.Temporal photoacoustic signals and images of small objects behind a scattering media will be shown.

1. Wave mixing and vibrometry in gain laser media

When performing interferometry on a scattering surface such as biological media, the use of a conventional interferometer results in sensitivity mainly limited to the SNR of one speckle grain. A convenient solution to compensate for the low spatial coherence of the complex signal wavefront is to introduce a dynamic wavefront adaption stage into the interferometer. This is usually done using holographic two wave mixing (2WM) in a nonlinear crystal inducing the beam coupling effects between the incident interfering signal and reference waves. It thus results in perfect spatial matching of the signal and self-diffracted waves leading to a very sensitive linear response of the interferometer with respect to phase changes of the signal wave [1]. An original approach to perform wave mixing and wavefront adaption consists in exploiting gain saturation in laser media. Such media offers the possibility of dynamic holography with laser gain and with a sub-ms response time, typically 100-200 µs [2-4]. These performances are superior to photorefractive crystals in particular in term of speed. The experimental setup used is shown in figure1. It consists of an incident 1W CW Nd-YAG at 1064 nm illuminating the sample under test and the 2WM is done by interfering the signal and plane wave reference wave into the Nd-YVO4 gain laser media which size is 5x5x5 mm. The crystal is diode pumped at 808 nm by a high power diode able of delivering 100W quasi CW-10ms pulse at 10Hz. The holographic gain region is about 300µm diameter and 5mm long. The crystal is anti-reflected coated at

808 and 1064 nm. The interference fringes create a volume hologram due to the gain saturation, ie the dependence of the gain versus the fringe intensity. An important characteristic of the experiment relies on the fact that we record both an amplitude and a phase volume gain grating. The model of 2WM developed in [3-5] takes account of this index spatial modulation which can be decomposed into the sum of two terms $\beta nr + \beta r$ respectively linked to the non resonant and the resonant contributions. Considering our experimental conditions it will be shown that the wavelength mismatch of 0.1 nm between the gain curves of Nd-YAG and of the Nd-YVO4 is responsible for the index grating (Kramers-Kronig relations) [5]. Usually this additional phase modulation is neglected but recent interferometric experiments may efficiently exploit the index contribution in laser gain media. As this refractive index modulation is local with respect to the position of the incident fringes it directly yields a linear response of the dynamic interferometer with a high sensitivity. In other terms, the detection is linear with respect to the small amplitude of vibration of the object structure illuminated by the Nd-YAG laser. We outline that in case of a purely amplitude gain grating the response of the interferometer would be quadratic. The two types of responses, linear and quadratic have been confirmed in experiments with vibrating frequencies higher than 10 kHz [3]. In this experiment due to the refractive index grating component the amplitude of displacement is of few A°.

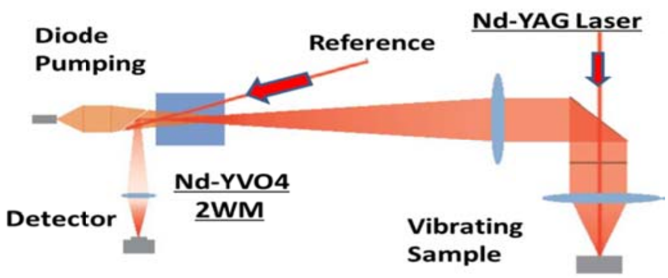

Fig 1. 2WM with diode pumped Nd-YVO4 laser gain media and applications to interferometry.

2. Application to Photoacoustic imaging

We also propose to apply this type of adaptive interferometer to probe the vibrations generated by a photoacoustic effect. In these experiments the acoustic wave is generated by local absorption of a short 4 ns laser pulse. This technique is well developed for 3D imaging in biological tissues where detection of the acoustic wave is made by conventional piezoelectric transducers. The presented all optical method has the potential advantage of realizing a non-contact detection with a much larger bandwith.The setup used achieve optical detection with the Nd-YVO4 adaptive interferometer [3]. The photoacoustic effect is generated using a pulsed 4ns - Q Switch 532 nm Nd-YAG laser delivering 150 mJ per pulse. When probing the surface of the sample with the adaptive interferometer it is possible to reconstruct the acoustic wave front and to image the object emitting the acoustic wave. Experimental results will be shown when using a small object of diameter 170 µm placed behind a clear gel of agar and a piece of cooked chicken breast to mimic a weakly scattering media as encountered in biophotonics applications. We demonstrate the possibility of using an adaptive holographic laser gain interferometer to probe acoustic waves generated by photoacoustic effect. Its sensitivity benefits from the gain grating index component due to the wavelength shift between the gain curves of Nd-YAG and Nd-YVO4. Moreover the fast response time of the interferometer (less than 100µs) enables to compensate parasitic vibrations (frequency <10 kHz) while being able to detect high frequency photoacoustic signals in the MHz range. These novel features open very significant characteristics for applications in nondestructive testing or in vivo biophotonics imaging.

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