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Self-starting vector phase conjugate laser oscillator in inverted Nd : YAG

[1]D.H.KIM, D.Udaiyan, R.P.M.Green, G.J.Crofts and M.J.Damzen

[1]*Division of Electronics and Information Technology, Korea Institute of Science and Technology, P.O.Box 131, Cheongryang, Seoul, Korea.*

The Blackett Laboratory, Imperial College, London SW7 2BZ, UK

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We report the operation of a self-adaptive vector phase conjugate laser (VPCL) oscillator which compensates intracavity polarization distortion and wavefront aberration simultaneously. The VPCL in Nd:YAG gain media produce an output with energy of 125mJ in a 20ns single-longitudinal-mode pulse at 10Hz, which is unaffected by intracavity polarization distortion.

I. INTRODUCTION

The generation of a phase conjugate wave has been the subject of much interest in high power lasers because it compensates for the phase distortion and the depolarization in a laser oscillator. The recent studies of spatial hole burning induced volume gain gratings show a high-diffraction efficiency greater than unity and a self-adaptive correction of phase distortion by the four-wave mixing interaction[1-3]. The phase conjugate laser oscillation in a self-intersecting loop geometry produces significantly different temporal, spatial and spectral modes from the free-running conventional laser systems.

The polarization state of a light wave that passes through a stressed optical component becomes distorted due to the polarization scrambling. Vector phase conjugation which removes the effects of polarization distortion has been observed in several experiments where the pump beam polarizations were properly arranged to improve phase conjugate efficiency[4-7]. In this work, we report the generation of complete time-reversed phase conjugate laser beams which correct polarization distortion and wavefront aberration simultaneously.

II. VECTOR PHASE CONJUGATE LASER OSCILLATOR

The experimental oscillator system is shown in Fig. 1. It consists of a 4% reflectivity output coupler(OC), two flash-lamp-pumped Nd:YAG amplifiers (G1,G2) in a double elliptic cavity with rods 100mm long and 6mm in diameter, and a nonreciprocal transmission element (NRTE) located between the amplifiers. The arrangement of amplifier G1 in the self-intersecting loop geometry has the form of a self-pumped phase conjugate mirror. The nonlinear mechanism in this system is based on FWM in the saturable gain medium (G1). The NRTE consists of a 45 degree Faraday rotator (FR) and a half-wave retardation plate between a pair of polarizers (P1 and P2) with parallel orientation to their transmission axes. These polarizers make the polarization state of the transmitted beams as p-polarized and eject the uncompensated polarized beams, s-polarized. This arrangement of elements produces different magnitudes of transmission in opposite directions around the loop. Control of the differential transmission factor is provided by a rotation of the half-wave plate. Two quarter wave plates, whose fast axes are 45-degree rotated to the transmission axes, make the pump waves counter-propagating circularly polarized. This arrangement of circularly polarized pumped DFWM induces nonlinear polarization, which has directly proportional vector components to any polarization state of the probe beam, owing to the tensor nature of the 3rd-order susceptibility in optically isotropic materials[8]. In order to investigate the polarization properties, the half-wave retarder which is the controllable polarization distorter is inserted inside laser oscillator loop.

III. OUTPUT CHARACTERISTICS OF VPCL

Initial intensity modulation in the gain medium is in-

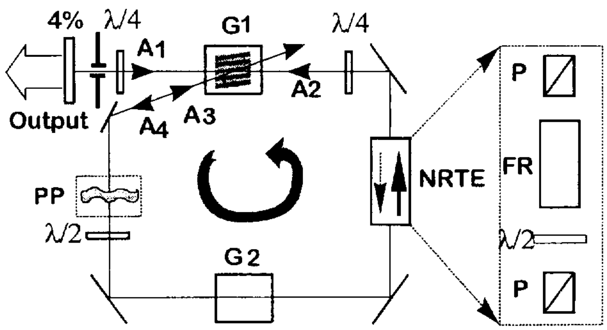

Fig 1. Schematic diagram of vector phase conjugate Nd:YAG laser oscillator.

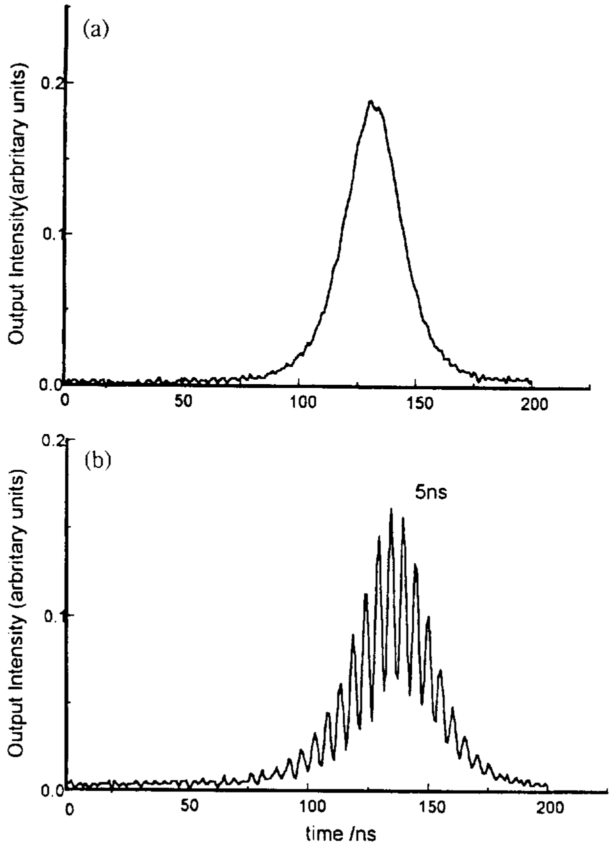

Fig 2. A temporal profile of the output, showing a smooth pulse of duration 20ns (a) and an occasional mode-beating pulse with a small temporal modulation of 5 ns (b).

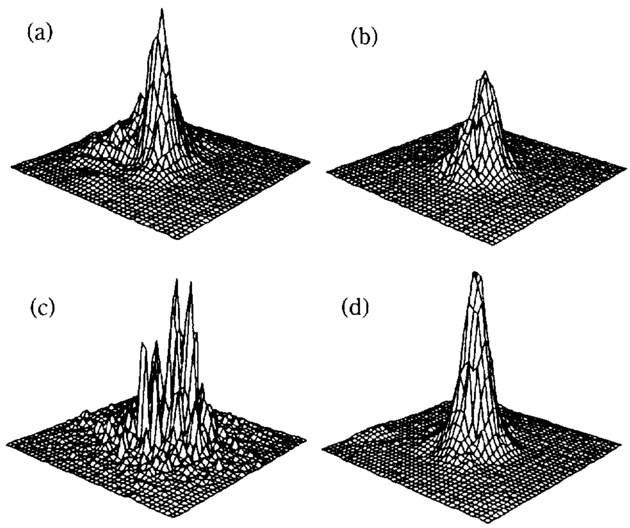

Fig 3. Spatial mode properties of VPCL oscillator: (a) multi-mode, (b) single mode, (c) with phase distorter in front of CCD, (d) phase distortion corrected.

duced by intersecting beams(A1 and A3) from spontaneous emission, and it induces gain modulation because of the spatial hole burning in the inverted Nd:YAG crystal. This gain grating diffracts the radiation in the loop configuration causing an enhancement of the amplified spontaneous emission flux. This diffracted radiation is also selected preferentially due to Bragg-matched scattering and produces constructive interference to enhance the growth of a gain grating. This parametric feedback involving the mutual growth of the gain grating leads to lasing in a single-longitudinal-mode due to the Bragg spectral selectivity.

When operated at 10Hz, the laser oscillator emits 125mJ of energy in a pulse of 20ns duration. The pulse output is temporally smooth and self Q-switched, as shown in Fig. 2(a). This short pulse is generated due to transient build-up and the depletion of the gain grating by the lasing radiation. A 10GHz Fabry-Perot measurement with spectral resolution of 1GHz shows distinct ring pattern. An oscilloscopic picture with a time resolution of <1ns presents the absense of mode beating. These results indicate the single-longitudinal-mode in the frequency domain because the mode beating between the adjacent longitudinal modes must have a longer modulation period than 5ns. Occasional mode beating with modulation of 5ns indicates a weak second mode at a mode spacing of 200MHz, corresponding to the loop length of 150cm formed by the transmission grating as shown in Fig. 2(b).

Fig. 3 compares three-dimensional spatial profiles of the output mode. Fig. 3(a) is the spatial profile in the case of an open intracavity aperture. Fig. 3(b) shows the generation of a stable gaussian-like mode when the intracavity aperture suppresses the high spatial frequency component by spatial filtering. Fig. 3(c) is the spatial profile distorted after passing the etched glass plate outside the laser oscillator. Fig. 3(d) shows the corrected spatial profile, which is unaffected even by the introduction of a phase distorter (etched glass plate) inside the cavity.

Fig. 4 represents a comparison of the output energy (p-polarized) and the uncorrected s-polarized component energy between the nonpolarization correcting scheme 4(a) and polarization correcting scheme 4(b), as a function of the angle of the intracavity polarization distorter (HW). When the angle is zero degrees, the probe beam(A3) passes the axis of the half-wave plate, its polarization state remaining unchanged. As the half-wave plate is rotated, the magnitude of p-polarization in the probe is reduced. Since the probe beam is orthogonal to the p-polarized pump beams (A1, A2) at 45 degrees, gain grating cannot be formed in the nonpolarization correcting scheme Fig. 4(a). On the other hand, as the circularly polarized pump beam can be decomposed into two orthogonal linear polarizations, the gain grating is always formed with half efficiency only. Therefore laser output does not fall to zero in

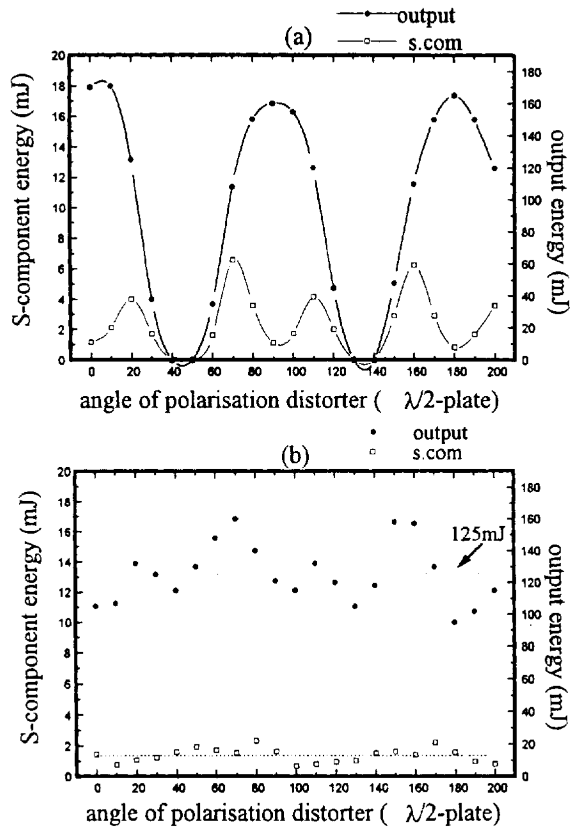

Fig 4. The output (p-polarized) energy and ejected beam (s-polarized) energy as a function of the angle of the half-wave plate for the nonpolarization correcting(a) and polarization correcting scheme(b).

any polarization state of the probe beam. The average output energy (p-polarized) in the polarization correcting scheme is comparatively decreased because of the unused component in forming the gain grating and because the losses in the two additional quarter wave plates. Furthermore, the uncompensated polarization component, s-polarized, has also been suppressed in the polarization preserving scheme. Fig. 4(b) shows that there is a small level of uncompensated s-polarized radiation, which cannot be corrected by this system because of thermal birefringence in a high gain amplifier. The fluctuation of the output energy in Fig. 4(b) could be minimised in a low gain amplifier (mean gain = 50), which would improve the fidelity of the VPCL[9].

IV. CONCLUSION

In conclusion, we have demonstrated a complete self-adaptive Nd : YAG laser oscillator in a four-wave mixing scheme that corrects the intracavity polarization distortion as well as the wavefront aberration. In addition, due to the dynamic build-up of the gain grating, the laser system produces self Q-switched SLM pulses without the conventional Q-switcher or the spectral filter.

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