SECOND HARMONIC GENERATION IN PERIODICALLY POLED NONLINEAR CRYSTALS WITH 1064 nm GAUSSIAN LASER PULSES*

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Received September 13, 2006

Fundamental output beam of 1064 nm wavelength emitted by a diode-pumped and passively Q-switched Nd:YAG microchip laser was frequency doubled in an 8 mm long periodically poled potassium titanyl phosphate (PPKTP) crystal. More than 12 μJ green pulse energy was obtained for 20 μJ fundamental pulse energy, corresponding to 60% second harmonic (SH) conversion efficiency. The power density of the fundamental pulse focused inside the nonlinear crystal was about 25 MW/ cm^2.

In order to maximize SH conversion efficiency, the operating temperature of the nonlinear crystal was controlled by using a thermoelectric cooler. The thermal acceptance of the PPKTP crystal was experimentally determined, resulting a full-width-half-maxim (FHWM) value of 5.7°C. The nonlinear coefficient of the PPKTP was estimated at 6.9 pm/V.

The present paper describes a laboratory work elaborated for master students of the Faculty of Physics from University of Bucharest.

Key words: microchip laser, second harmonic generation, periodically poled crystal.

1. INTRODUCTION

Quasi-phase-matching is an alternative technique to birefringent phase-matching [1]. A periodic structure in a nonlinear crystal which reset the phase relation between propagating beams each time it reaches π by changing the sign of the nonlinear coefficient would enable continued energy flow from the fundamental frequency wave to the second harmonic. The practical approach to obtain a periodic structure in ferroelectric crystals involves forming regions of periodically reversed spontaneous polarization and thus domains where the sign of the effective nonlinear coefficient d_{eff} is changed every coherence length. This property combined with small size of diode-pumped solid-state lasers, allow the development of compact and efficient lasers with output wavelengths ranging from the UV to the near-to-mid infrared.

* Paper presented at the 7th International Balkan Workshop on Applied Physics, 5–7 July 2006, Constanța, Romania.

Materials, such as PP LiNbO3 (LN) and LiTaO3 (LT) offer the possibility for noncritical phase matching for the largest nonlinear coefficient, d_{33}, of the crystals. A 42% single pass 1064-nm cw Nd:YAG frequency-doubling efficiency has been demonstrated in a 53 mm long PPLN crystal [2]. Periodically poled KTP crystals have been developed as an alternative to the better established PPLN technology [3]. Even the effective nonlinear coefficient of PPKTP crystals is lower than PPLN, KTP has the advantage of room temperature operation without photorefractive damage. Efficient frequency-doubling was demonstrated in PPKTP crystals pumped by high-power pulsed Nd:YAG lasers [4, 5].

In this paper I present the results of frequency doubling in PPKTP and crystals pumped by a Nd:YAG microchip laser.

2. EXPERIMENTAL SET-UP

As a pumping radiation for microlaser we used 808 nm from a pulsed SDL-2472P1 laser diode with 3W maximum cw power, 900 Hz frequency, 210 μs pump pulse duration. The experimental set-up is shown in Fig. 1. The pumping radiation is coupled to the microlaser by two aspherical lenses (AL1, AL2). The microlaser customer designed and made by CASIX-China, consists in a 3 mm diameter, 3.5 mm thick piece of Nd:YAG crystal doped at 1.1% Nd, bonded by optical contact to a 3 mm diameter, 1 mm thick piece of Cr:YAG crystal with 75% initial transmission at 1064 nm. Both crystals have outside flat faces, orthogonal to the microlasers cavity axis.

The unbounded side (M1) of the Nd:YAG crystal is dielectrically coated to transmit more than 90% of pump 808 nm light and have a reflectivity higher than 99.8% at 1064 nm.

In Fig. 2 is shown the diagram of pulse power stability measured with a piroelectric detector PE10 couplet at the PC. We can see the standard deviation of the pulse power is about 0,6 %.

Transversal intensity profile and temporal profile are shown in Fig 3.

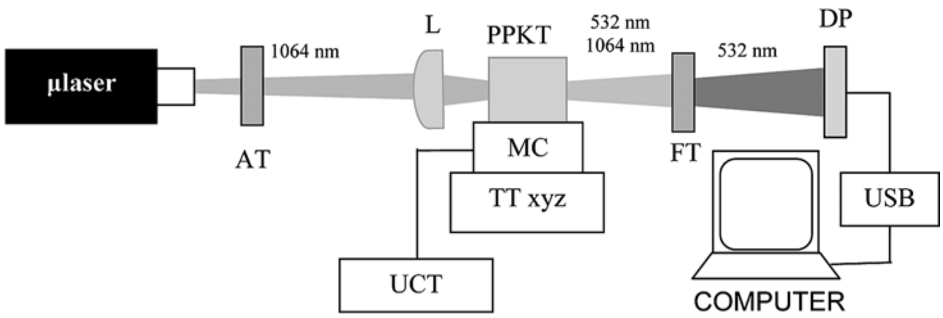

Fig. 1 – Experimental setup.

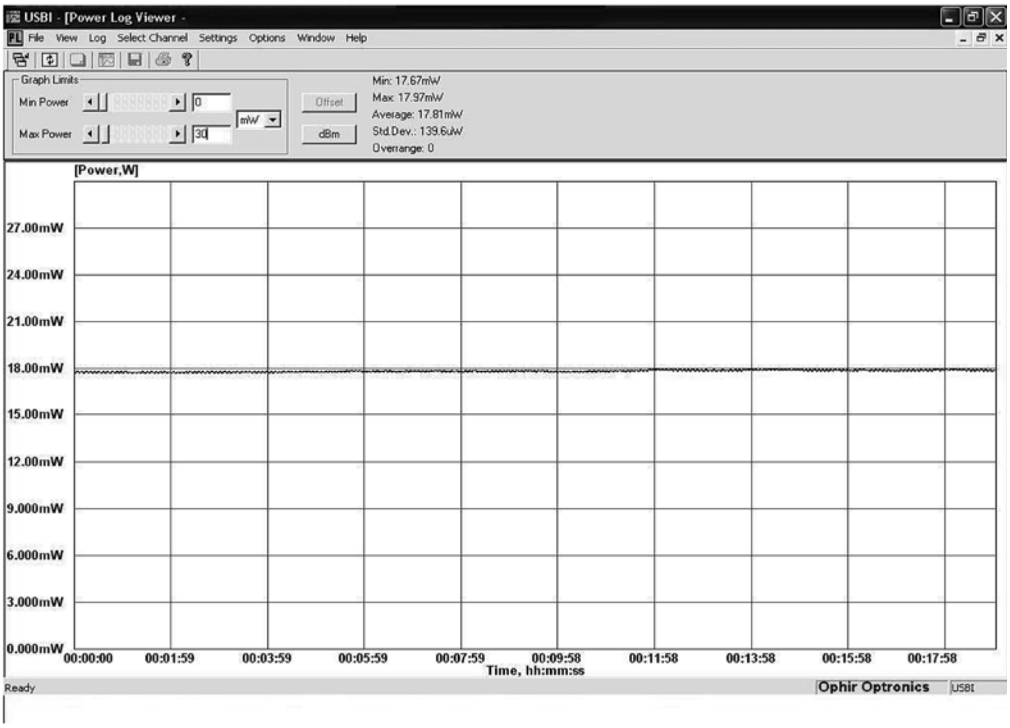

Fig. 2 – Diagram of pulse power stability.

The output face of the Cr:YAG (M2) have a reflectivity of 70% at 1064 nm. The output parameters of the passively Q-switched Nd:YAG microlaser are presented in Table 1.

Table 1

Pulse energy	**Pulse duration**	**Repetition rate**	**Beam waist radius**	**Beam divergence**
22.4 μJ	1.5 ns	905 Hz	170 μm	> 2 mrad

3. RESULTS AND DISCUSSION

The first order of quasi-phase matching (QPM) is realized by changing the sign of the nonlinear coefficient after each coherence length ($l_c = \frac{\lambda}{4(n_{2\omega} - n_\omega)}$). Considering the value of the nonlinear coefficient d_{33} off 16.9 pm/V, the theoretical effective nonlinear coefficient for a 50% duty cycle PP KTP crystal is $d_{eff} = \frac{2}{\pi} d_{33}$ = 10.7 pm/V. This value is larger than the effective nonlinear coefficient of the conventional type II crystal (3.18 pm/V). So the PPKTP crystals are

suitable for frequency doubling of low and medium power microchip lasers. We used a PPKTP crystal with 50% duty cycle, $1 \times 2 \times 8$ mm^3 made by Raicol-Crystals, Israel. The PPKTP crystal was mounted on a heat sink controlled by a thermoelectric cooler. We measured a temperature acceptance bandwidth of 5.78°C at FWHM, Fig. 4, in good agreement with the calculated value for a 8 mm long PPKTP crystal (5.8°C).

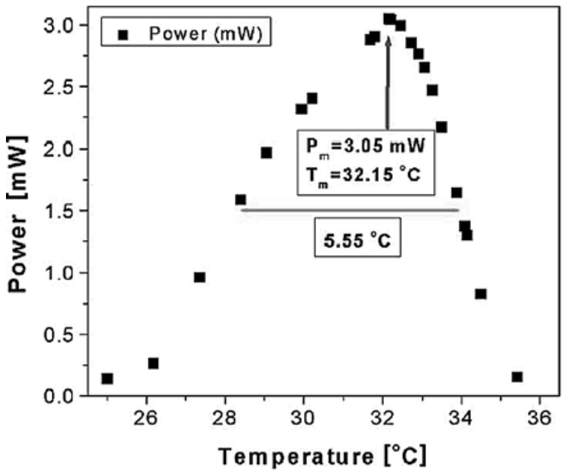

Fig. 4 – Second harmonic power as a function of crystal temperature.

The 1064 nm laser radiation was focused on crystals with different focusing lense (*L*) to obtain beam average waist radius of 110 μm. Using a set of calibrated attenuators (*AT*) we changed the intensity of the incident 1064 nm radiation

In Fig. 5 is shown the waist radius of the microlaser after the focusing lens (the focal distance of the lens was 500 mm).

The axial position of the crystal was adjusted relative to the fundamental beam waist to obtain maximum SH conversion efficiency. We measured fundamental and SH average power using a LASERSTAR OPHIR powermeter.

Fig. 6 illustrates the variation of SH radiation power with IR radiation power averaged for 905 Hz pulse repetition rate. SH radiation with as much as 10 μJ output energy has been obtained for 18 μJ pulse energy of the fundamental radiation focused with a waist radius of 101 μm.

The measured SH conversion efficiency function of IR intensity radiation is shown in Fig. 7. Highest conversion efficiencies measured for incident beams 8 mm long PPKTP crystals with 101 μm waist radius was 50%. I have calculated the internal conversion efficiency for the uncoated PPKTP crystal taking into account the refractive losses on y_1 the input face at 1064 nm and on y_2 the output face at 532 nm.

Because the confocal parameter of the beam with 110 μm waist radius ($b \cong 71$ mm) is much larger than the PPKTP crystal length ($L = 8$ mm), we can

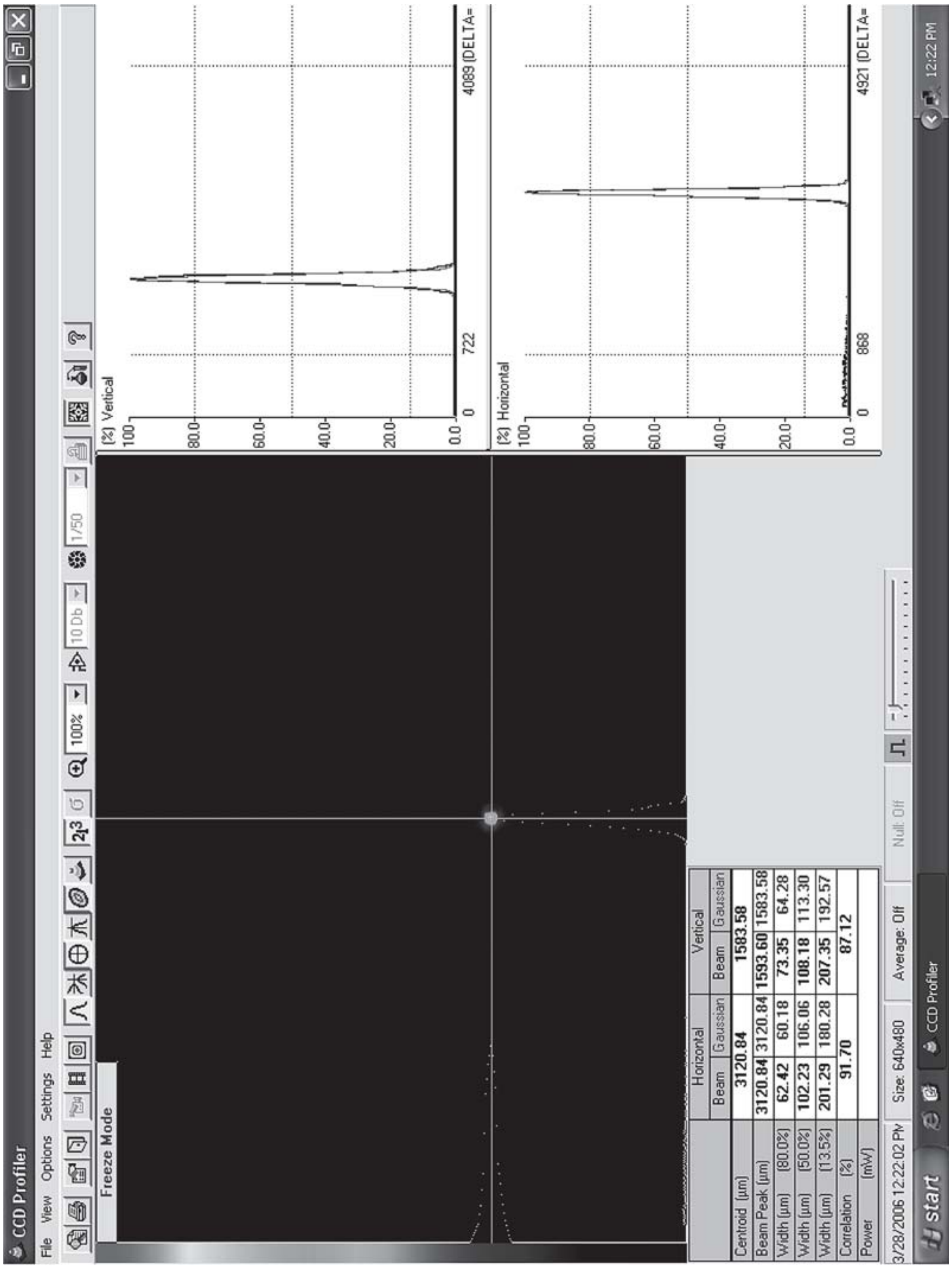

Fig. 5 – Transversal intensity profile of the microlaser after the focusing lens.

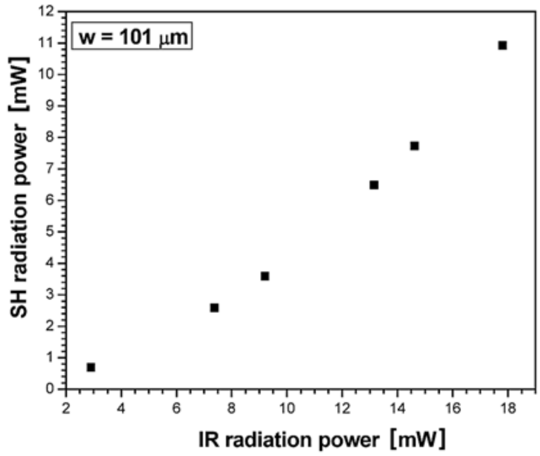

Fig. 6 – Measured SH radiation power dependence in the IR radiation power at 101 μm pump beam waist radius.

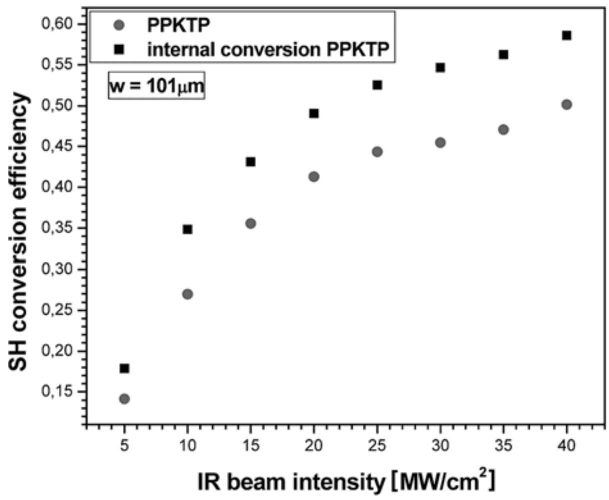

Fig. 7 – SH conversion efficiency *versus* IR beam intensity at 101 μm pump beam waist radius.

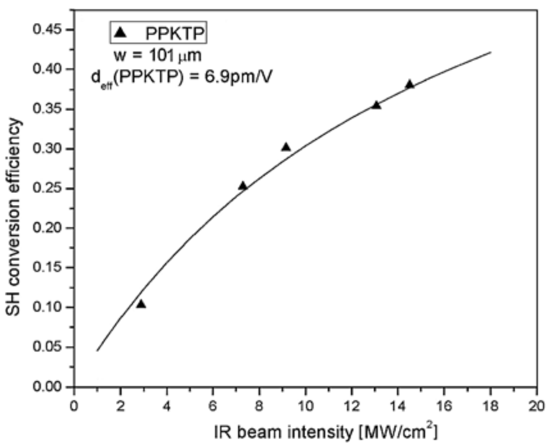

Fig. 8 – Measured and theoretical SH conversion efficiency for PPKTP.

approximate an unfocused beam inside the frequency doubler (L/b = 0.11 << 1). In order to estimate the effective nonlinear coefficient of the PPKTP crystal we have compared the experimental data with the theoretically calculated energy conversion efficiency as shown in Fig 8. We obtained a good agreement between theoretical and experimental values for d_{eff} = 6.9 pm/V, about 65% from the effective nonlinear coefficient of an ideal PPKTP sample with 50% duty cycle. The theorethical curve was obtained using the equations [6]:

$$\eta = \gamma_1\gamma_2 \frac{3.76}{\tau w_i^2} \int_{t=-\infty}^{t=\infty} \int_{r=0}^{r=\infty} Exp\left[-\frac{2r^2}{w_i^2} - \frac{t^2}{(0.6\tau)^2}\right] Tanh^2 \cdot \left[l_g Exp\left[-\frac{r^2}{w_i^2} - \frac{t^2}{2(0.6\tau)^2}\right]\sqrt{\kappa 1.88\gamma_1 I_a}\right] rdrdt \tag{1}$$

$$\kappa = \frac{8\pi^2 d_{eff}^2 g_\alpha g_\lambda}{n_1 n_2 n_3 \varepsilon_0 c \lambda^2} \tag{2}$$

κ is the nonlinear coupling coefficient, I_a is fundamental peak irradiance, d_{eff} is the nonlinear effective coefficient of the crystal, ε_0 is the permittivity of vacuum, λ is the fundamental wavelength (1064 nm), g_α and g_λ are the reduction coefficients owing to the limited phase matching spectral bandwidth and angular acceptance width of the nonlinear crystal, c is speed of light, n_1, n_2, n_3 are the refractive indices of the interactions waves, w_1 is the fundamental beam radius, l_g is the crystal length, τ is the FWHM pump pulse-width.

4. CONCLUSION

In conclusion, I proved the possibility to develop efficient miniature green laser systems based on PPKTP crystals pumped by the fundamental frequency of diode-pumped passively Q-switched Nd:YAG microchip lasers. Applications of these devices are in holographic interferometry and fiber based monitoring systems for biological processes and environmental contaminants.

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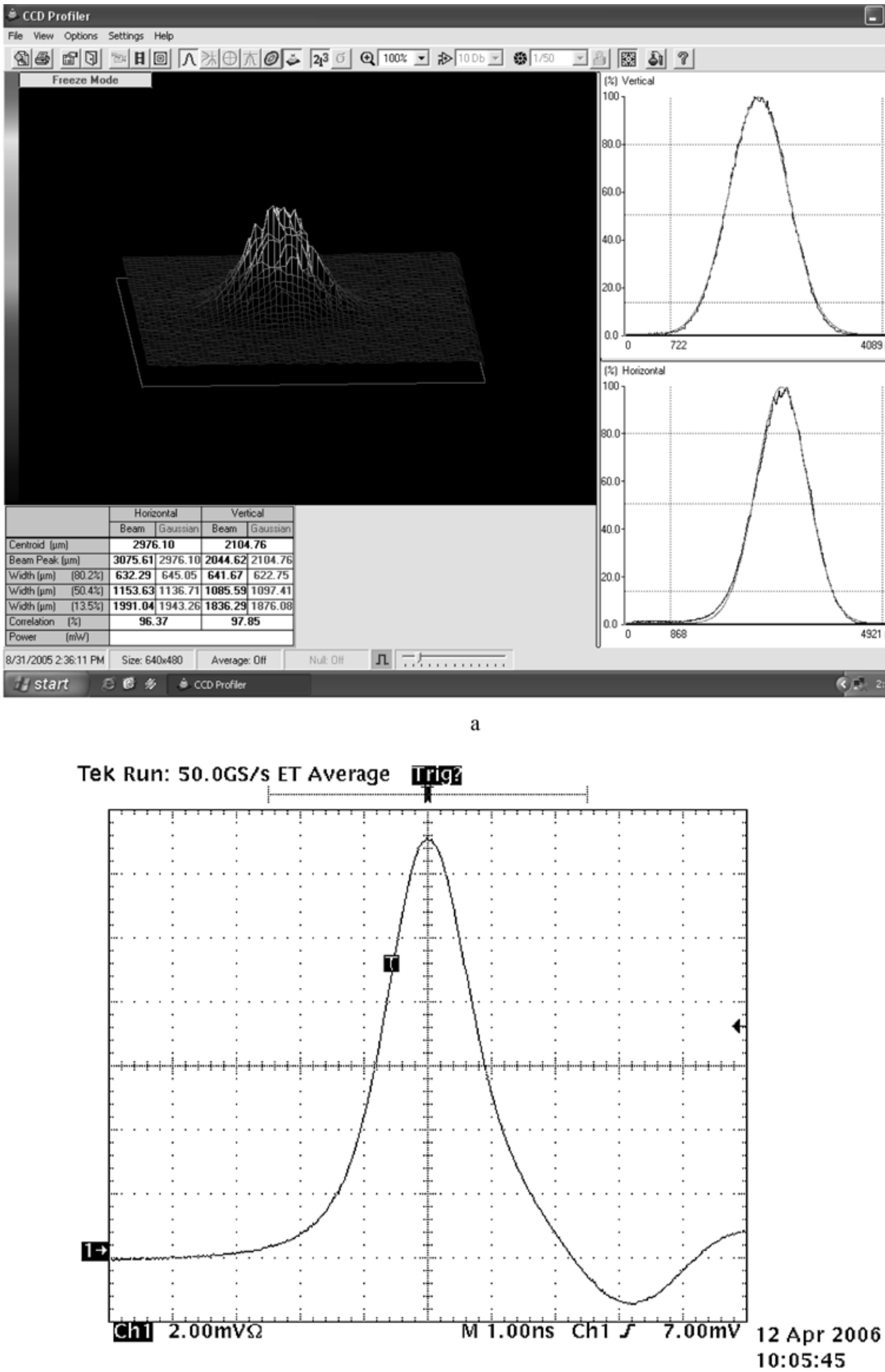

b

Fig. 3 – a) Transversal intensity profile; b) temporal profile of the microlaser.