Efficient resonant doubler of CW tunable single-frequency radiation with a 1-THz automatic quasi-smooth scan range

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ABSTRACT

Demonstrated for the first time is automatic quasi-smooth scanning of an resonant frequency doubler synchronously with the frequency of a CW auto-scanned Ti:Sapphire laser within a 1-THz frequency range, which is limited only by the spectral width of non-linear crystal phase matching.

Keywords: resonant frequency doubler, single-frequency laser, smooth scanning, second harmonic generation.

1. INTRODUCTION

Technique of efficient frequency doubling of CW laser radiation in an external high-Q optical resonator is widely used for generation of radiation in UV and visible spectrum ranges [1-5]. In comparison with relatively simpler techniques that use PPLN crystals [6] and fibers [7,8], frequency doubling in external cavity can provide significantly higher powers of second harmonic. Resonant frequency doubler in tandem with single-frequency tunable laser enlarges spectral range of the laser, and parameters of smooth radiation frequency tuning in short-wavelength spectral range are determined by the potential of resonant doubler. Usually, the range of smooth laser frequency scanning supported by the existing resonant frequency doublers in automatic mode lies between few and dozens of GHz [9-11]. The limiting factor is at that the range width, in which the external cavity length can be varied. It depends on control element (PZT etc.), though owing to large spectral width of nonlinear crystal phase-matching it is possible in principle to tune the external resonator smoothly or quasi-smoothly in the range of ~ 1 THz for fundamental radiation and accordingly in the range of ~ 2 THz for its second harmonic [12] without nonlinear crystal adjustment.

In this work a resonant doubler is described, which is capable to automatically follow a laser frequency when it changes within 1-THz-wide scopes. In the developed doubler this range is restricted only by spectral width of nonlinear crystal phase-matching.

2. EXPERIMENT

The resonant frequency doubler (see Fig. 1) with 15-mm-long LBO crystal has a bow-tie-shaped ring cavity, two of its mirrors being PZT-driven. The system for automatic adjustment of the doubler resonator's transmission peak to match the input radiation frequency uses the Hansch-Couillaud method [13] and consists of two control rings (the fast one, bandwidth ~ 70 kHz, and the slow one). The smooth scanning range of the doubler cavity is limited by the slow PZT and stretches to about 6 GHz.

The photograph of developed doubler resonator is shown in Fig. 2. The resonator has rigid compact design, what minimizes passive instability of optical elements position. Nonlinear crystal temperature is retained automatically at the level 50-55 degree so as to minimize temperature effects in nonlinear crystal.

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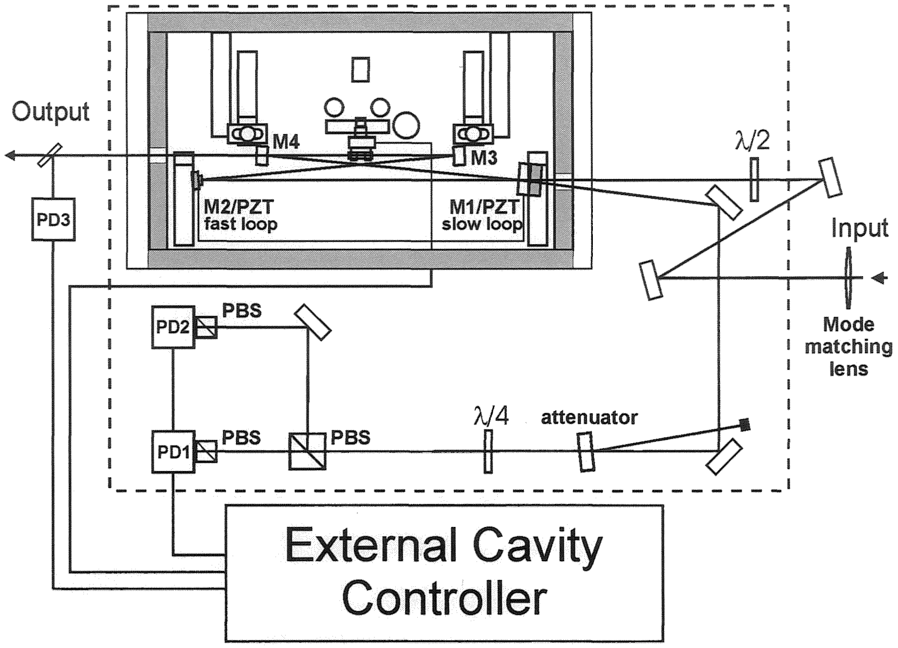

Fig. 1. Schematic design of the Resonant Frequency Doubler: M3, M4, concave mirrors (R=100 mm); M1, input coupler, slow-PZT-driven mirror; M2, fast-PZT-driven mirror; PBS – polarization beamsplitter cubes; PD1, PD2, photoreceivers of stabilization system; PD3, control photoreceiver.

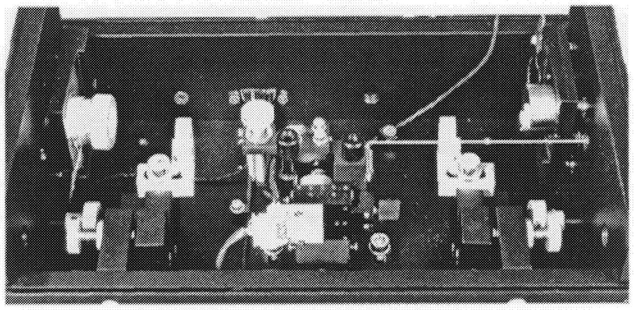

Fig. 2. Optical resonator of the doubler.

In order to broaden substantially the scanning range of the resonant doubler in lock with the laser, for the first time a method was used of automatic re-locking of different transmission maxima of the doubler cavity to the input frequency that can be changed within 1 THz. The system operates in the following way: if the input laser frequency changes within the smooth scanning range of the doubler cavity the system keeps the transmission peak of the doubler resonator in lock with the input frequency. As the input laser frequency passes beyond this range the cavity of the frequency doubler is automatically re-tuned to the beginning (or to an otherwise set position) of the scanning range and then is locked in to the input laser frequency and follows it continuously. The number of automatic cycles when the input frequency is re-locked to successive transmission peaks of the doubler cavity can be arbitrarily large, and the domain of automatic quasi-smooth frequency scanning that is composed of multiple smooth scanning ranges (~ 1-6 GHz wide) is only limited by the spectral width of the non-linear crystal phase matching, the latter being as wide as few to dozens of THz.

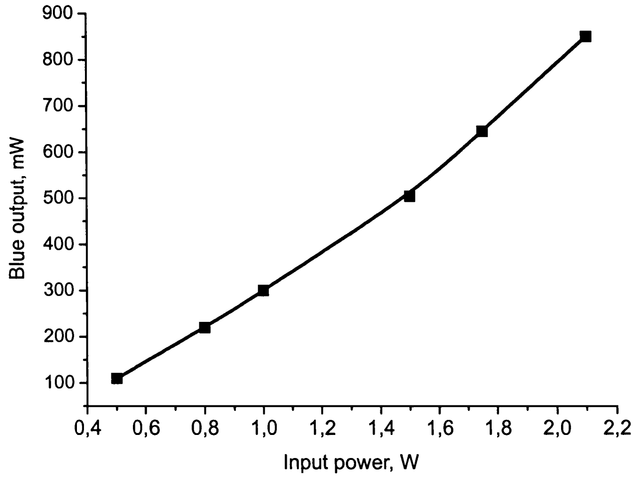

Fig. 3. A typical dependence of generated by developed doubler second harmonic power on power of input radiation at 800 nm produced by Ti:Sapphire laser. Maximum second harmonic power at 400 nm is 850 mW when input power is 2.1 W.

The diagrams shown in Fig. 4 illustrate the process of automatic quasi-smooth tuning of resonant doubler. In the instants when the doubler resonator returns to its starting position so as to commence the new cycle of smooth scanning, a short-term drastic decrease of second harmonic power takes place. For this short time the system of experimental data registration can be disabled by the signal of electronic control unit of resonant doubler, therefore from the point of view of experimental system this scanning is smooth in wide spectral area. The power of second harmonic radiation in different cycles of smooth scanning is to remain constant (see the lower diagram).

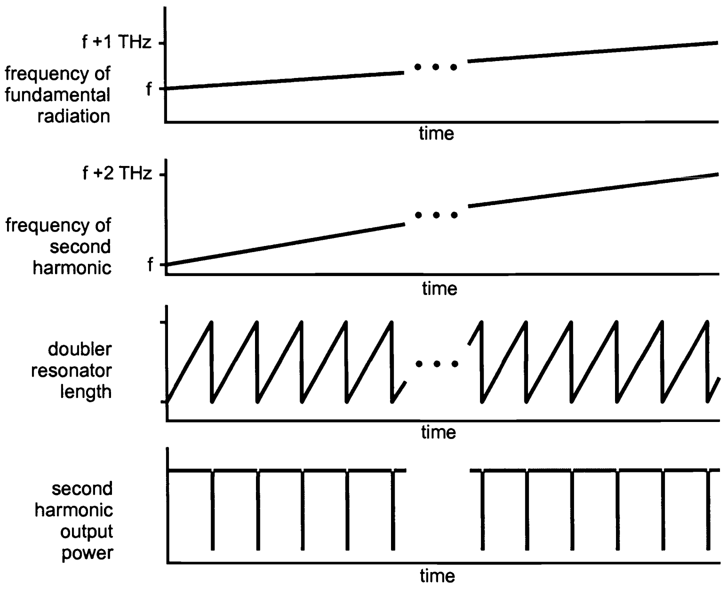

Fig. 4. Diagrams demonstrating the process of automatic quasi-continuous tuning of the resonant frequency doubler synchronously with the frequency of the fundamental radiation within a wide spectral range. Each cycle of resonator length adjustment on the second diagram below corresponds to continuous frequency scan of the second harmonic radiation.

Experimental dependence of second harmonic power on scanning frequency in the range between 387.1493 THz and 387.1588 THz is given in Fig. 5. Studies were carried out with the use of single frequency Ti:Sapphire laser 899-29 Ring Autoscan II with the ability to automatically and quasi-smoothly scan the output frequency within a range in excess of dozens of THz, the range width of smooth scanning is at that ~ 10 GHz.

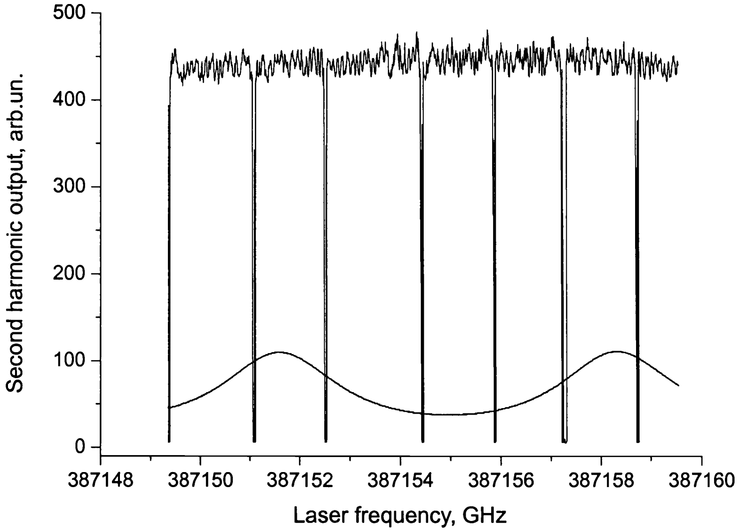

Fig. 5. Experimental dependence of second harmonic power on scanning frequency

Vertical lines in Fig. 5 correspond to short-term dips of second harmonic power when automatic re-locking of input radiation frequency takes place. Typical time of re-locking amounts to 1 ms. Input radiation frequency re-locking were accomplished by the doubler cavity automatically when input radiation changed by the value of 1.3-1.9 GHz. Measurements of absolute fundamental frequency and of its changes were carried out by means of wavelength meter that is a part of the laser 899-29 Ring Autoscan II. Fig. 5 shows also simultaneously registered transmission function of the etalon (FSR = 6.8 GHz) of this meter. When input radiation frequency was smoothly varied by 9.5 GHz, the second harmonic frequency changed automatically and quasi-smoothly (with five frequency re-locking) by 19 GHz.

Further it was interesting to examine how far the resonant doubler can follow the input radiation frequency when the nonlinear crystal position remains intact. In our experiment the widest range of automatic quasi-smooth tuning of resonant doubler was about 1 THz, the second harmonic frequency changed at that by ~ 2 THz. Presented in Fig. 6 are experimental dependences of second harmonic power at the beginning of this 1-THz-wide range (when input radiation frequency changes from 386.0622 THz up to 386.0723 THz), inside of the range (input radiation frequency lays between 386.2867 THz and 386.2968 THz) and at the end of this range (input radiation frequency changes from 386.9366 THz up to 386.9463 THz). The system of input frequency auto-re-locking was adjusted so that at the beginning of each smooth scanning range of laser frequency the doubler tuned synchronously with it in the range of 2-3 GHz, and then frequency re-locking took place every time when input radiation frequency changed by ~ 0.5 GHz. This change (~ 0.5 GHz) corresponded to free spectral range of doubler cavity, i.e. the re-locking was carried out with the use of each next transmission peak of resonant doubler. With wider ranges of smooth scanning, frequency re-locking was realized using every four, or five, or six transmission peak of resonant doubler. Selection of frequency auto-re-locking sytem regime could be fulfilled by means of electronic control unit settings.

A considerable decrease of second harmonic power, concerned with approach of radiation frequency to a scope of nonlinear-crystal phase-matching spectral range, can be seen in Fig. 6c. With another setting of doubler resonator, instability of second harmonic generation can take place when input radiation frequency is in the vicinity of spectral range of nonlinear crystal phase-matching (Fig. 6d).

Note also that when doubler resonator have wider scanning ranges between frequency re-locking (Fig. 5 and Fig. 6d), second harmonic power dips reach 100%, whereas when doubler resonator have narrower scanning ranges between frequency re-locking (Fig. 6 a-c) second harmonic power dips in the moments of frequency re-locking do not exceed, as a rule, 50%.

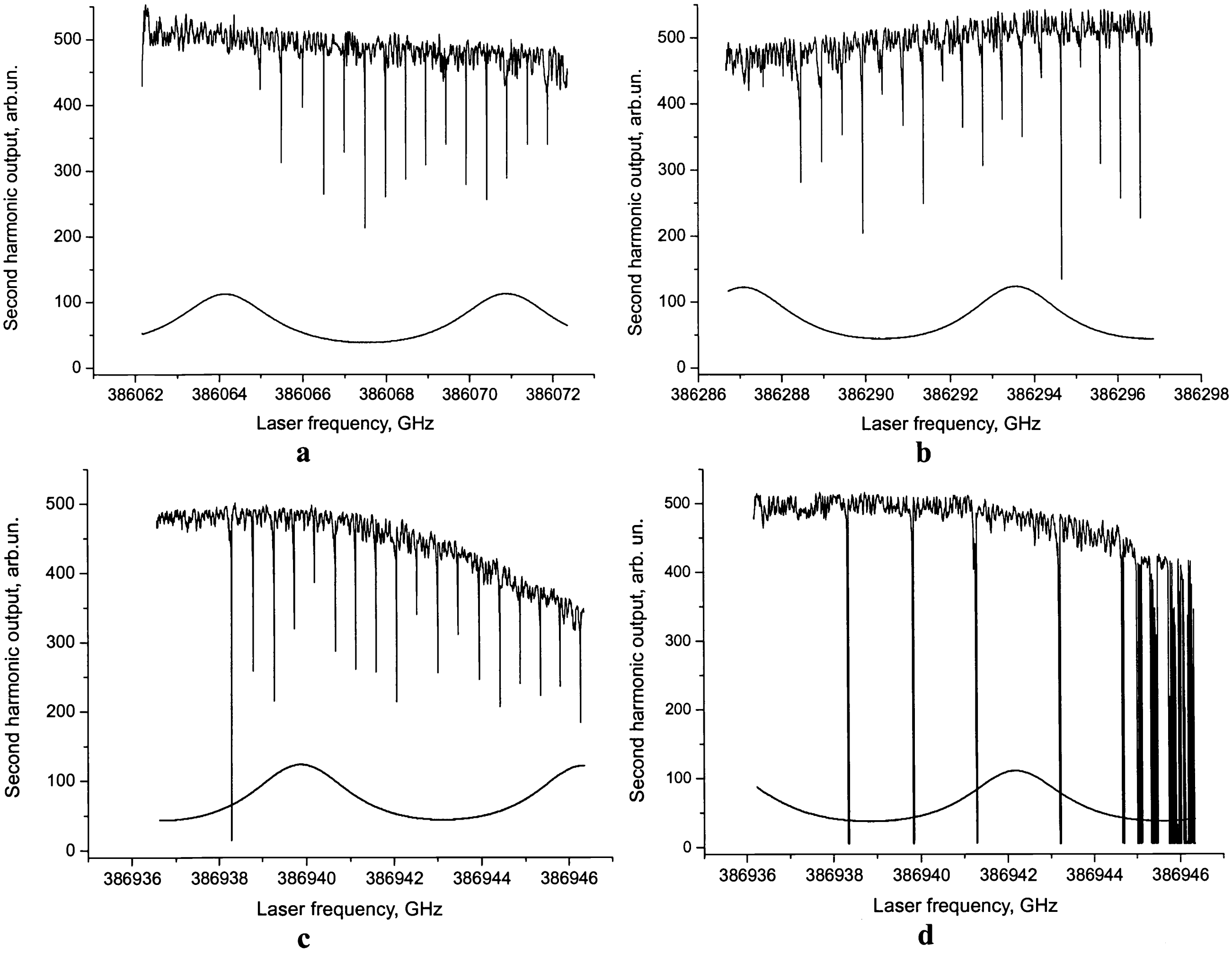

Fig. 6. Experimental dependencies of the second harmonic output power upon the wavelength of the fundamental radiation: Figs. *a* and *b* correspond to automatic quasi-continuous scanning of the frequency doubler approximately in the beginning of the 1-THz domain (Fig. *a*) and within a spectral range about ~ 0.3 THz from the beginning (Fig. *b*); Figs. *c* and *d* illustrate the behaviour of the second harmonic output power when the fundamental wavelength approaches the edge of the phase matching domain of the non-linear crystal in different modes of automatic frequency re-locking.

3. SUMMARY

In this paper we have demonstrate the validity of the suggested method of automatic quasi-continuous scanning of the external frequency doubler resonator synchronously with the output frequency of the CW auto-scanned Ti:Sapphire laser within a 1-THz range. When the laser frequency is detuned (continuously or quasi-continuously) by up to 1 THz the resonator of the frequency doubler automatically follows the frequency of the laser, the position of the non-linear crystal remaining unchanged. The width of the working spectral range of this method (1 THz for the fundamental radiation) is only limited by the spectral width of the phase matching of the non-linear crystal. The quasi-continuous scan range for the second harmonic radiation reaches, accordingly, 2 THz and consists of multiple domains with continuous smooth scanning, each being ~1 to 5–6 GHz wide.

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