Wide-autoscanned narrow-line tunable system based on CW Ti:Sapphire/Dye laser for high precision experiments in nanophysics

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ABSTRACT

We present developed computer-controlled tuneable laser system based on CW narrow-line Ti:Sapphire/Dye laser which is meant for laser-optical characterisation of quantum dot properties. The full set of laser system options allows it to cover a spectral range from 275 to 1100 nm while having the output line width around 0.5-1 GHz. The system includes a built-in high-precision radiation wavelength meter and a system of automatic control over the spectrally selective laser elements, thus providing the possibility to automatically set the output radiation wavelength to the absolute precision of 1 GHz (0.004 meV) and to perform continuous scanning of the output radiation line in a specified spectral range.

Keywords: Ti:Sapphire laser, Dye laser, tunable laser, laser spectrometer

1 INTRODUCTION

The possibility to detune automatically the output wavelength of the tuneable laser allows full automation of spectral analysis or spectral measurement procedures [1-4]. In their simplest configuration, such auto-scanned lasers have electromechanically driven selective element that provides control over the laser output wavelength through electronic signals. However, a single selective element produces a relatively broad laser radiation line. When narrower output is necessary the second, more spectrally selective element, is introduced into the laser cavity. The process of laser output wavelength detuning within a wide range requires that both these selectors (the first, coarse, and the second, fine) be adjusted synchronously. However, the working, or free, spectral range (FSR) of the fine selector is substantially narrower than that of the coarse selector. Because of this the synchronous detuning of coarse and fine selectors within a wide spectral range involves a specific algorithm, following which the fine selector must be reset to the beginning of its FSR after it reached the maximum possible detuning, whereas the coarse selector is continuously adjusted along the whole gain contour of the laser and defines roughly a comparatively broad output spectral band, within which the fine selector isolates a narrower band.

In case the laser cavity contains additional spectrally sensitive elements (for example, a non-linear crystal for intra-cavity frequency doubling) the problem of automatic detuning of the laser output wavelength is further complicated. This work reports and analyses newly developed algorithms of automatic control over such systems.

2 LASER SYSTEM DESCRIPTION

The diagram of employed linear resonator of the tuneable laser is shown in Fig. 1. This layout features the possibility of implementation on the basis of both a CW Ti:Sapphire laser and a dye jet laser, including configurations with intra-cavity frequency doubling. A three-component birefringent filter (BF) [5] and a thin (h = 0.3–0.5 mm) Fabry-Perot étalon are used as radiation selectors. BF is rotated by a step motor (one step corresponds to BF detuning by 0.04 nm) and the thin etalon is declined with the help of a galvanometer drive. The second analogous galvanometer may be used in order to adjust the non-linear crystal. The laser is able to operate both in the fundamental wavelength generation

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mode and in the mode of second harmonic generation, delivering either pure second harmonic radiation or both the second harmonic and a fraction of fundamental radiation in the output.

The laser is controlled by a computer through USB 2.0 interface and an electronic unit including step motor controller, galvanometer drivers, as well as a high-precision radiation wavelength meter. This latter meter allows tuning the laser to a user-specified wavelength with absolute accuracy of 0.001 nm.

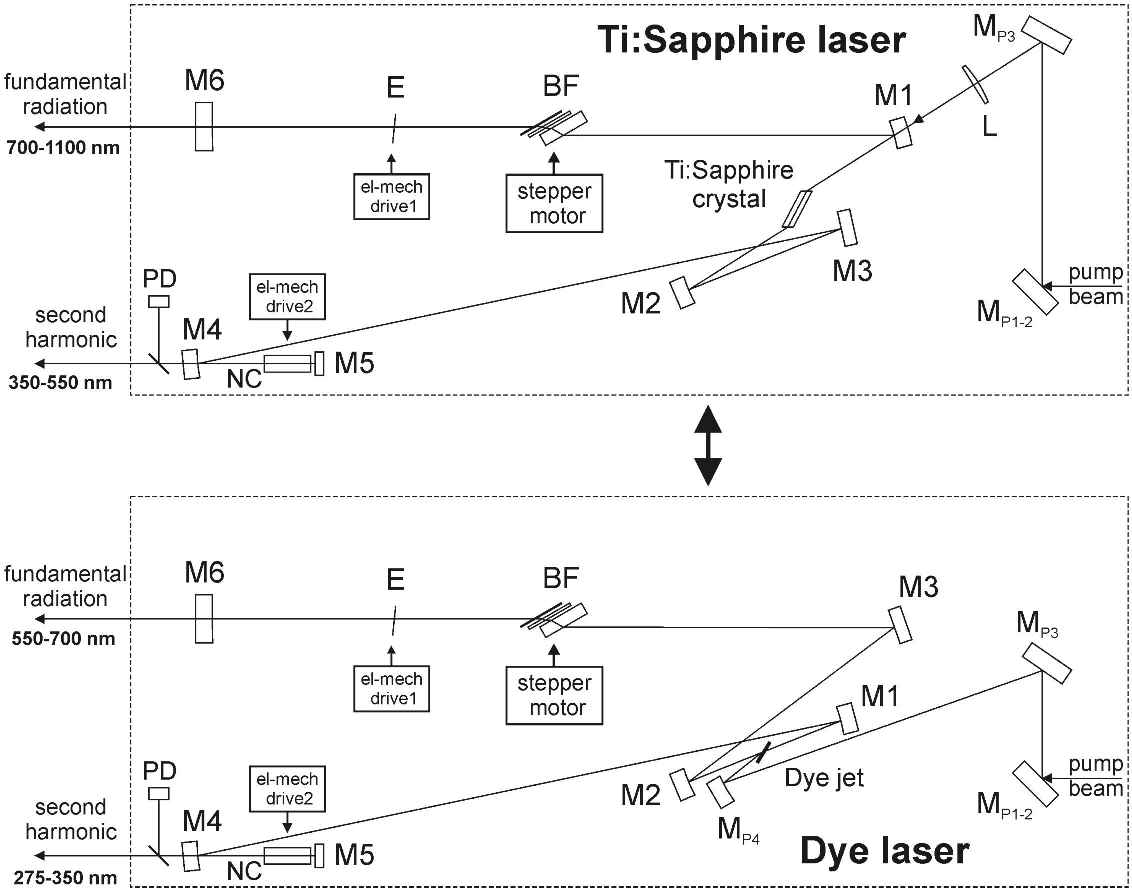
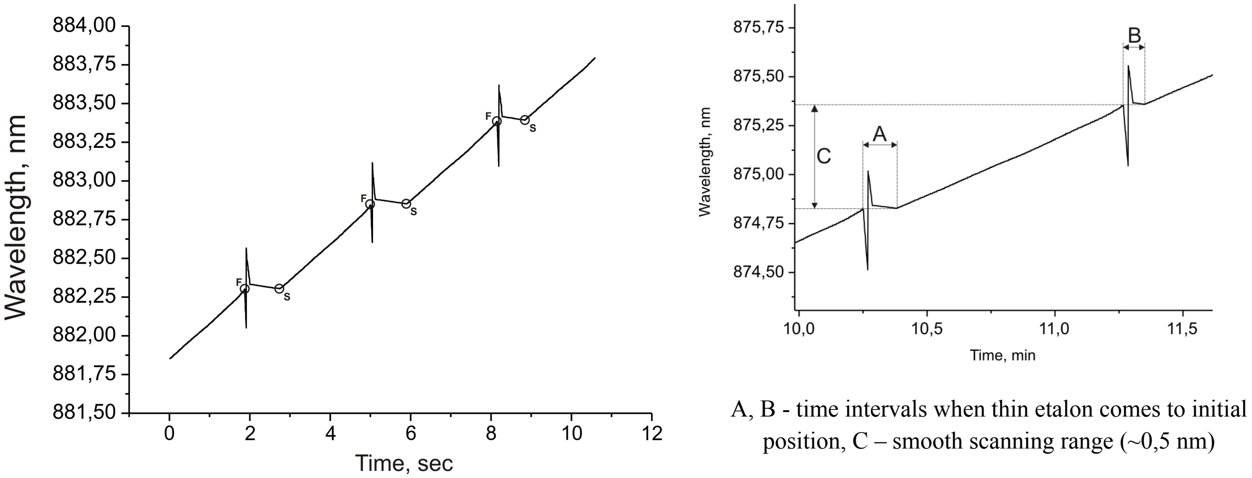


Fig. 1. Layout of the combined CW narrow-line Ti:Sapphire/Dye laser: M_{P1-4} - pump mirrors, M1, M2, M4 - spherical mirrors (M1/M2: R=75 mm for Dye laser and R=100 mm for Ti:Sapphire laser), M3, M5 - flat mirrors, M6 - output coupler, BF - 3-plate birefringent filter, E – solid thin Fabri-Perot etalon, PD - photodetector, L - lens.

When using the fundamental radiation only, two selective elements have to be controlled for automatic spectral detuning of the laser output line - BF and thin étalon. There are two algorithms for synchronisation of detuning of these two selectors, active and passive ones. For passive synchronisation it is necessary to calibrate with the help of a radiation wavelength meter all BF positions, store them and use these calibration data for maintaining synchronous detuning of BF and the thin etalon at different output radiation wavelengths. This method's drawback consists in the mandatory re-calibration after a change of BF or even after the same BF was re-aligned. The active synchronisation method of these two selectors requires an additional photo-detector for monitoring, for example, the intensity of radiation reflected off the bi-refringent filter. As the two selective elements go out of sync, the intensity of radiation reflected from BF increases, which fact could be used as an error signal for correction of the BF position. However, the introduction of one photo-detector for intensity of reflection from BF immediately requires a second photo-detector that monitors the total intensity of the laser radiation (for normalisation of the signal from the first detector), thereby complicating the system design.

The new method of synchronous detuning of BF and the thin étalon we have developed works in a wide spectral range and is based on an analysis of the dependence of the laser output wavelength at the moment when the thin étalon is reset to its initial position. The laser radiation wavelength curve during this transition has the form of a derivative of a bell-shaped function (Fig. 2). The minimum and maximum of this derivative are only symmetrical with respect to the final (or initial in the cycle of continuous scanning of the radiation wavelength) value of the laser wavelength during resetting of the thin étalon in the case when transmission maxima of BF and the thin étalon coincide at the end of the continuous scanning of the laser output line. If, conversely, the transmission maxima of these two selectors do not coincide at the end of the continuous laser line scan then the laser wavelength dependence curve will not be symmetrical with respect to the last laser output wavelength in the cycle of continuous scanning. The degree of this dissymmetry is a measure of misalignment between the spectral position of BF and thin étalon's transmission peaks at the boundary of the continuous wavelength detuning range of the laser output. Measurement of asymmetry degree of the laser output wavelength dependence during the process of resetting the thin étalon into its initial position makes it possible to correct the BF position between cycles of smooth laser line scanning and to continue synchronous scanning of the two selectors in the subsequent cycle of continuous scanning of the laser output line.



A, B - time intervals when thin etalon comes to initial position, C – smooth scanning range (~0,5 nm)

Fig. 2. Automatic tuning of laser wavelength: symbol "F" is used to mark the end of the continuous laser output line scanning range and symbol "S" is used similarly for the beginning of the continuous scanning range, *i.e.* smooth scanning of the laser radiation line is carried from the wavelength marked with "S" until the wavelength marked "F". Subsequently, from "F" to "S" the étalon is reset to its initial position. For the duration of this reset process the system is not operational because during this time the end of the previous continuous scanning range is being "spliced" to the beginning of the next similar range. For the duration of this service procedure the intake of experimental data related to effects of the system's output radiation is blocked on a special signal active until the end of this procedure.

The proposed method is fairly universal and only requires approximate initial synchronisation of BF and thin étalon's detuning rates necessary for these two selectors to provide at least one range of continuous output line scanning, which amounts to one or two FSR ranges of the thin étalon. Further on, prior to the following cycle of smooth laser output wavelength scanning, the BF position is corrected and both selectors continue to be detuned quasi-synchronously. It is important that detuning rates of these two selectors do not have to be precisely identical for continuous scanning of the laser output line. Smooth scanning of the laser radiation line will be achieved even if the spectral transmission peaks of BF and the thin étalon are somewhat mismatched, although this misalignment cannot exceed a half of the thin étalon's FSR. Failing this the laser output wavelength will jump to the neighbouring transmission peak of the thin étalon.

In the course of experimental trial of this technique within the 840–990-nm range (on the basis of a narrow-line Ti:Sapphire laser made by Tekhnoscan Co.) the rates of spectral detuning of the BF and thin étalon transmission peaks were equalised in the centre of this range around 915 nm and then at the boundary of each continuous laser line scanning range the BF position was adjusted again by the proposed method. This allowed us to detune the laser output line automatically and quasi-continuously within the entire range from 840 to 990 nm. Quasi-smooth automatic scanning of laser line in spectral range from 869,5 to 880,5 nm is shown in Fig. 3. Fig. 4 shows examples of screen interface during work of the system in automatic regime.

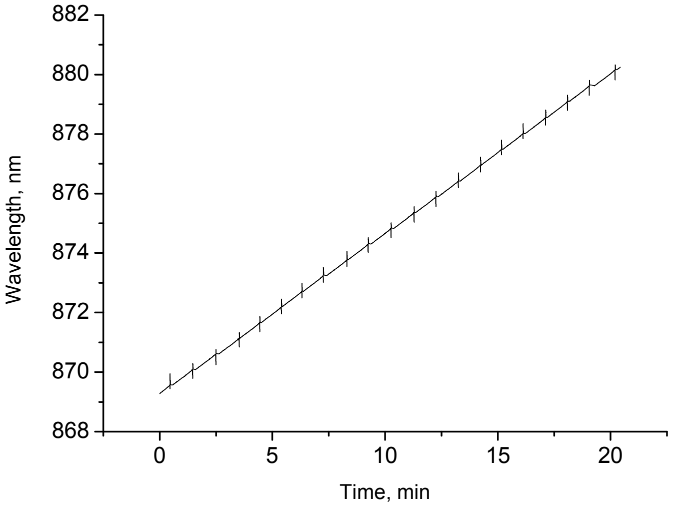
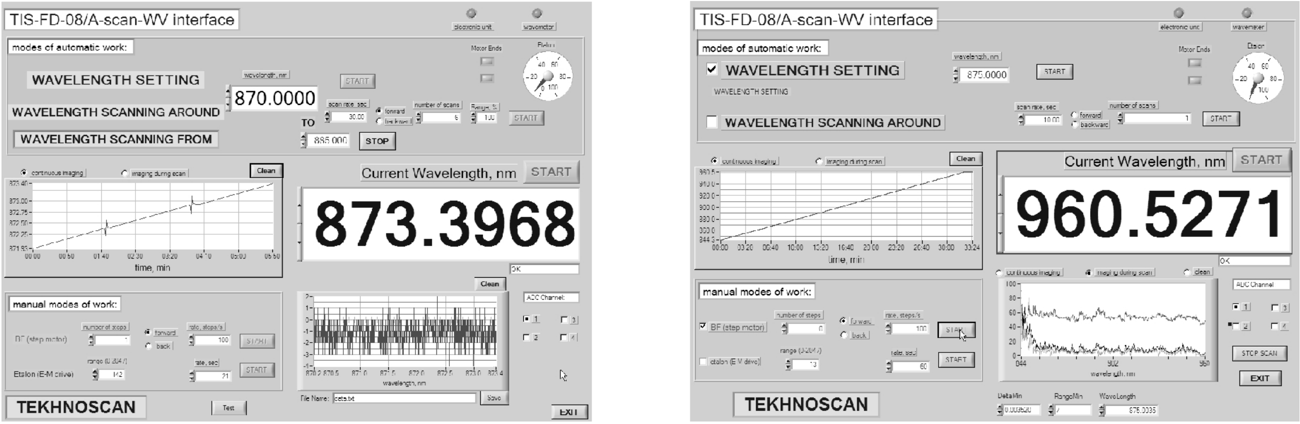


Fig. 3. Quasi-smooth automatic scanning of laser line in spectral range from 869,5 to 880,5 nm.


TIS-FD-08/A-scan-WV interface

modes of automatic work:
wavelength, nm: 870.0000
TO 885.000
scan rate, sec: 30.00
● forward ○ backward
number of scans: 6
Range, %: 100
Current Wavelength, nm: 873.3968
OK
● continuous imaging ○ imaging during scan
manual modes of work:
BF (step motor) number of steps: 1 ● forward ○ back rate, steps/s: 100
Etalon (E-M drive) range (0-2047): 142 rate, sec: 21
ADC Channel: ■ 1 ☐ 2 ☐ 3 ☐ 4
File Name: data.txt

TIS-FD-08/A-scan-WV interface

modes of automatic work:
☑ WAVELENGTH SETTING
wavelength, nm: 875.0000
☐ WAVELENGTH SCANNING AROUND
scan rate, sec: 10.00
○ forward ○ backward
number of scans: 1
Current Wavelength, nm: 960.5271
OK
● continuous imaging ○ imaging during scan
○ continuous imaging ● imaging during scan ○ clean
manual modes of work:
☑ BF (step motor) number of steps: 0 ● forward ○ back rate, steps/s: 100
☐ etalon (E-M drive) range (0-2047): 13 rate, sec: 60
ADC Channel: ■ 1 ☐ 2 ☐ 3 ☐ 4
DeltaMin: 0.003520 RangeMin: 7 WaveLength: 875.0035

Fig. 4. Examples of screen interface during a work of the system in automatic regime.

With other optical sets detuning of the Ti:Sapphire laser output line was available within 700–1100 nm range. An original laser design used in our system [6,7] allows easy combination of a Ti:Sa laser and a dye jet laser in the same resonant cavity by a simple exchange between a Ti:Sa crystal holder and a dye jet fixture together with corresponding cavity mirrors. This allows detuning the laser output line across the 550–700 nm range with three dye solutions (R110, R6G, and DCM) and two sets of optics (550–620 nm and 620–700 nm).

The spectral range between 275 and 550 nm is covered with the help of intra-cavity frequency doubling of the Ti:Sa (350–550 nm) or the dye laser output (275–350 nm). Adjustment of the non-linear crystal (LBO for Ti:Sa lasers and BBO for dye jet lasers) is likewise performed automatically by a system of active synchronisation between the non-linear crystal detuning and that of the thin étalon.

Parameters and modes of generation of such computer-controlled tuneable laser system (Fig. 5) are in many ways suitable for efficient solving of problems in the fields of nano-science and nano-technology. An important problem in this area is characterisation of semiconductor nano-particles possessing quantum-dimensional properties (quantum dots, wells, and quantum threads) according to their optical parameters. These quantum nano-structures exhibit quasi-atomic discrete energy spectra depending on their size and composition. For instance, typical absorption line widths of isolated quantum dots lie within 0.05–0.1 MeV (0.4–0.8 cm^{-1}), which corresponds to 12.1–24.2 GHz. Therefore, one is able, by means of a tuneable laser with the output line width in the vicinity of 1–2 GHz, to record such absorption lines with sufficient precision and to determine their shape. The use of three-component BF and a thin étalon in a linear CW Ti:Sa laser provides the output radiation line at the level of 1 GHz, whereas in a linear CW dye laser the radiation output line width provided by these selectors amounts to approximately 2–2.5 GHz.

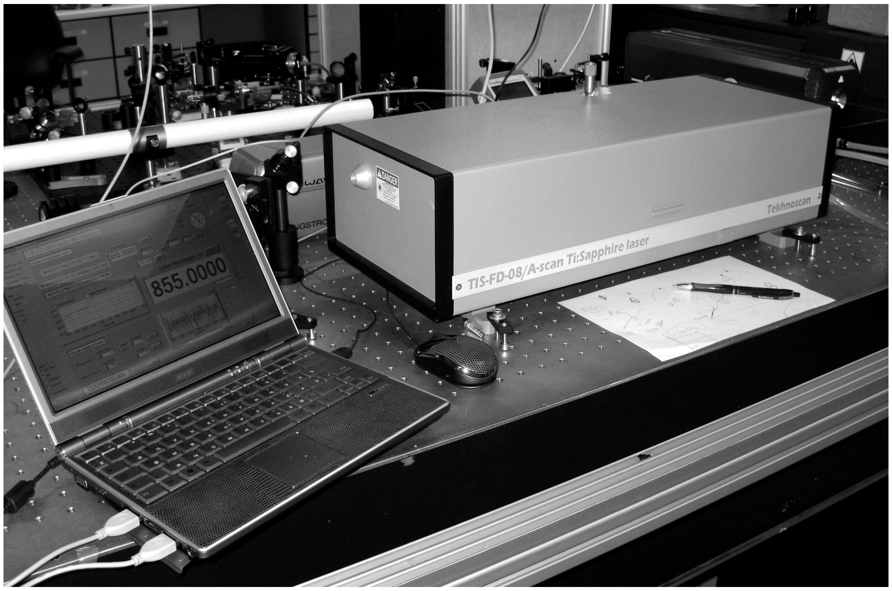


Fig. 5. Wide-autoscanned narrow-line tunable system based on CW Ti:Sapphire laser

3 CONCLUSIONS

We propose in this paper a new technique for controlling two selective elements (BF and thin étalon) of a CW tuneable laser that provides fully automatic quasi-continuous detuning of the laser output line within ultra-wide spectral range from 275 to 1100 nm. This technique only requires continuous control of the laser output wavelength and does not depend on additional photo-detectors or encoders for reading the position of wavelength selectors. This method may be used in various narrow-line CW lasers (solid-state, dye, hybrid fibre/bulk, &c) in which BF and a thin étalon are used for wavelength selection. It can be also applied successfully in systems where a prism or a diffraction grating is used instead of BF filter.

The proposed technique allows relatively simple and efficient automation of quasi-continuous laser output line detuning within a broad spectral domain. Such automatically scanned laser systems are required for solving many problems in nano-science and nano-technology.

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