Quantum Electronics **34** (12) 1083 (2004)

OPTICAL METROLOGY AND QUANTUM FREQUENCY STANDARDS

PACS numbers: 42.62.Eh; 06.30.Ft
DOI: 10.1070/QE2004v034n12ABEH002917

State of the art and outlook for investigations in the field of optical metrology and quantum frequency standards

M.A. Gubin

The Editorial Board of Quantum Electronics decided to publish in several issues the selected papers devoted to the study and applications of quantum frequency standards (QFSs) and optical metrology. The latter includes frequency measurements in the range from 10^{13} to 10^{15} Hz, which was earlier virtually inaccessible for calibration in absolute frequency units (hertz) specified by the primary cesium frequency standard. In this field, annual reviews are published in the world literature and two – three international conferences are held. The selected papers reflect mainly the state of the art at Russian scientific centres.

The role and place of QFSs among other modern directions in physics are well known, and advances in this field reflect to a great extent the development dynamics of quantum radiophysics and its contribution to the world science. Beginning with the solution of practical air navigation problems in the 1940–50s, this topic served as a 'motor' for many fields in quantum electronics such as the development of a variety of narrowband (kilohertz) and ultra-narrowband (subkilohertz) tunable lasers, precision (both in resolution and sensitivity) laser spectroscopy, including methods of ultra-deep cooling, confinement, and manipulation of atoms and molecules, and finally for an amazingly spectacular combination of ultrafast femtosecond processes with extremely stable continuous-wave lasing.

This achievement of physics of ultrashort pulses performed a true revolution in the QFS field. The method was developed for the first time for efficient and convenient measurements of optical frequencies, i.e., a 'clock mechanism' was created capable of dividing in one stage a frequency in the visible range by a factor of $10^4 - 10^5$ down to the cesium standard frequency (9.1 GHz). This step allowed one to 'combine' together different laser and microwave frequency standards separated by tens and hundreds of terahertz. An advantage of such a combination is the transfer of output parameters from one device to another, which allows the user to approach an 'ideal' standard by selecting the required combination of properties (the relative frequency stability, spectral width, repeatability, reproducibility, accuracy).

M.A. Gubin P.N. Lebedev Physics Institute, Russian Academy of Sciences, Leninskii prosp. 53, 119991 Moscow, Russia

Received 15 November 2004
Kvantovaya Elektronika **34** (12) 1083 (2004)
Translated by M.N. Sapozhnikov

The reverse influence of 'frequency' measurement technologies on 'temporal' technologies based on ultrashort pulses is no less fruitful.

The phase control (in particular, phase stabilisation) of spectral components formed by a train of ultrashort pulses by comparing with the QFS frequency allows one to change the pulse shape, provide the coherence between pulses from different femtosecond lasers, and vary the phase delay between the envelope and carrier. All this provides qualitatively new opportunities for using ultrashort pulses in problems of nonlinear optics of superstrong fields, spectroscopy, metrology, telecommunications, and other applications.

Stable master oscillators, for example, quartz oscillators play an important role in the QFS hierarchy. The typical frequency stability of most popular quartz oscillators used in wrist watches is $\sim 10^{-6}$ per day. At present, a concept of an extremely miniature (1 cm^3 in volume) atomic clock is developed (and the technology is being rapidly elaborated) which provides a stability of 10^{-11} per day and is based on two-frequency semiconductor lasers and the effect of coherent population trapping in Cs vapours. The improvement of frequency stability by five orders of magnitude along with a small size of such a clock allows one to solve many problems of navigation, recognition, and coding in a new way, and to organize the mass production of clocks, for example, in mobile telephones.

The diversity of 'clock' transitions, methods for recording narrow reference lines, mass–size requirements, the global scale of the problem itself, and the development of highly precise 'time-coordinate' field available at any place on Earth and in space provide the natural basis for a wide international cooperation.

The presented papers show that Russian researchers make a noticeable contribution to the time and frequency metrology in the world. Because these papers cannot reflect, of course, all the variety of QFS studies, several recent reviews devoted to this field are also presented [1–4].

References

1. Basov N.G., Gubin M.A. *IEEE J. Sel. Topics Quantum Electron.*, **6**, 857 (2000).
2. Baklanov E.V., Pokasov P.V. *Kvantovaya Elektron.*, **33**, 383 (2003) [*Quantum Electron.*, **33**, 383 (2003)].
3. Udem Th., Holzwarth R., Hänsh Th.W. *Nature*, **416**, 233 (2002).
4. Ye J., Schantz H., Hollberg L.W. *IEEE J. Sel. Topics Quantum Elctron.*, **9**, 1041 (2003) and other papers in the issue.