RESEARCH AND DEVELOPMENT OF ATOMIC FREQUENCY STANDARDS IN THE NATIONAL INSTITUTE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY

Mizuhiko Hosokawa, Masatoshi Kajita, Kyoya Fukuda, Hiroyuki Ito, Motohiro Kumagai, Kensuke Matsubara, Ying Li, Hiroshi Ishijima and Takao Morikawa

National Institute of Information and Communications Technology
Nukui-kita 4-2-1, Koganei, Tokyo 184-8795, JAPAN
Email: *hosokawa@nict.go.jp*

In April 2004, the Communications Research Laboratory (CRL) and the Telecommunications Advancement Organization of Japan (TAO) were merged and reorganized into a new organization, the National Institute of Information and Communications Technology (NICT), an incorporated administrative agency. The activity on time and frequency research and development in CRL has been fully succeeded by NICT. In this paper, we will show the activity on the research and development of the atomic frequency standards. The main subjects are the following three. They are the operation and improvement of an optically pumped primary standard NICT-O1, development of Cs atomic fountain standards and a Ca^+ ion optical frequency standard.

NICT-O1

NICT-O1 (Fig. 1), an optically-pumped-cesium primary frequency standard, formerly called as CRL-O1, has been operational since April, 2000. The accuracy evaluation data has been sent to BIPM twice a year in average. Details on the accuracy evaluation of the standard is described in the reference [1]. The best accuracy among these data is 6 x 10^{-15} [2]. Due to the baking of the vacuum chamber, its operation stopped for several months in 2004. The operation has restarted since December 2004. The results in 2005 are shown in Table 1 [2]. In the table, *d*(NICT) denotes the fractional frequency deviation of TAI measured by NICT-O1 and *d*(BIPM) denotes the fractional frequency deviation of TAI determined by BIPM with all primary frequency standards' data, *d*(NICT) denotes that measured by NICT-O1 and *u*(NICT) is the total uncertainty of NICT-O1. All values are expressed in 10^{-15}.

Table 1. Accuracy evaluation result of NICT-O1 in the first half of 2005

MJD	*d*(BIPM)	*d*(NICT-O1)	*u*(NICT-O1)
53424-53434 (2005.02.23-03.05)	5.0	10.4	±8.5
53469-53479 (2005.04.09-04.19)	4.2	0.0	±8.5

Fig. 1.　NICT-O1

Cs-Fountain

The first fountain apparatus using the 1D-launching has been constructed since 1999 and the first Ramsey spectrum was observed at 2002. Since then, the S/N ratio has been improved. The first fountain has a disadvantage in its design, distance between optical trap and microwave cavity is as long as 67cm. In spite of the disadvantage, a stability of 3 x 10^{-15} has been achieved. The second fountain with 1D-launching has been completed in 2005 [3]. The distance between optical trap and microwave cavity is reduced down to 45 cm.　Also the operation became easier by reducing the size of the trap chamber.　The Ramsey signal obtained by the second fountain is shown in Fig. 2 and an Allan variance of the fountain standard with respect to a reference H maser is shown in Fig. 3. Its frequency stability is much better than that with the first fountain.

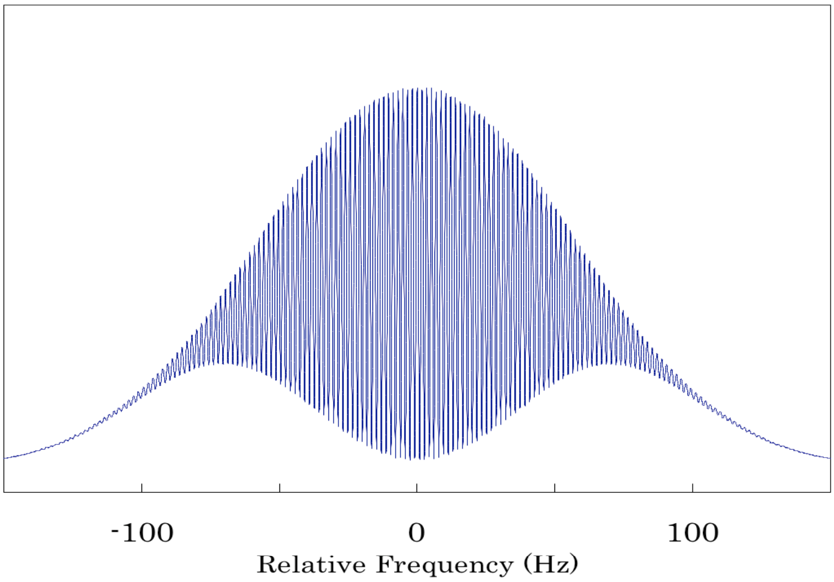

Fig. 2. The Ramsey signal obtained by the second fountain

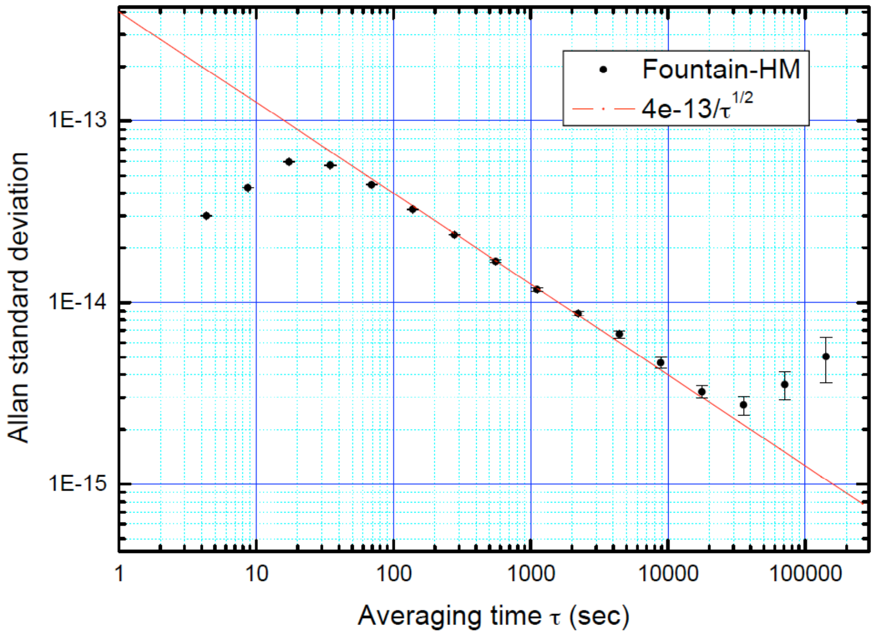

Fig. 3 The Allan variance between the second fountain and a reference H maser

Optical Frequency Standard with Ca^+ Ion

Aiming at measuring the spectrum of forbidden transition of single Ca^+ ion, we are now developing a new ion trap system. Natural line width of the $4s^2S_{1/2}$ - $3d^2D_{5/2}$ forbidden transition (729 nm) is as narrow as the order of 0.1 Hz. Hence this transition has a potential to be a very good optical frequency standard. Theoretical investigation shows that the trapped $^{43}Ca^+$ ion can be cooled enough to be localized within the Lamb-Dicke region [4, 5]. The frequency shift factors were also estimated that the frequency uncertainty lower than 10^{-15} would be attainable.

So far, an ion trap apparatus has been constructed (Fig. 4). Single Ca^+ ion has been trapped inside the electrode, and the quantum jump signal with a single $^{40}Ca^+$ ion has been observed [6].

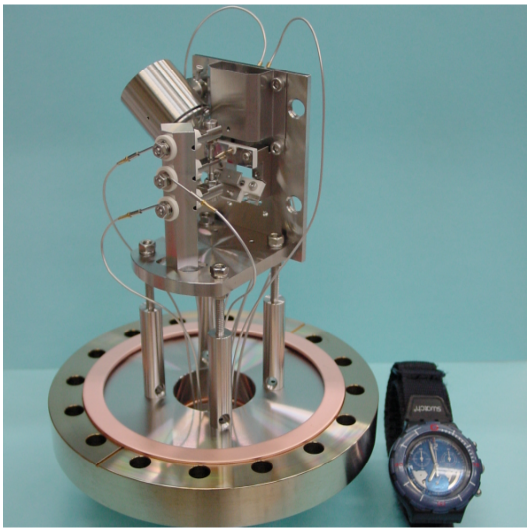

Fig. 4. Ion trap for single Ca^+ ion

For the laser cooling of the ion, a transfer cavity system has been developed, which is useful to stabilize the frequencies of multiple cooling (397 nm region) and repumping (866 nm region) lasers simultaneously [7]. To observe the $4s^2S_{1/2}$ - $3d^2D_{5/2}$ forbidden transition (729 nm), a narrow linewidth laser is being developed. A few tens Hz linewidth and a stability of 10^{-13} for the laser are achieved [8]. To measure the optical frequency, we have used a femtosecond optical comb system Menlo FC 8003 and we have evaluated its performance [9]. Details on this subject is shown in the other paper in this General Assembly [10].

Other Research Activities

In addition to the subjects shown above, our group has conducted several basic researches. High resolution spectroscopy using a thin cell [11] is one of them. This research gives useful information to develop compact atomic clocks. Theoretical analysis has been given for the properties of cold polar molecules trapped by the dc electric field [12]. The precise measurement of spectrums of cold molecules makes it possible to measure the temporal change of the ratio of masses of proton and electron. Research on the precise frequency measurement and relativity has been conducted. By transporting commercial clocks to mountain area, gravitational red shift has been measured [13].

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