(News Release)

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"Lasing" operation in an ultrasonic vibration using a MEMS oscillator

～Towards on-chip highly precise and high frequency micromechanical oscillators～

Nippon Telegraph and Telephone Corporation (NTT, CEO: Hiroo Unoura, Tokyo) has succeeded in fabricating a novel ultrasonic oscillator by applying a principle analogous to an optical laser,[*1] which is widely used as a highly purified light source, to a microelectromechanical systems (MEMS).[*2] The frequency purity of the output vibration is less than 1 part in1,000,000.
This result will be published in the American science journal "Physical Review Letters" (dated March 18) demonstrating a micromechanical device working on a totally novel mechanism.
A part of this study was supported by Japan Society for the Promotion of Science (JSPS, President: Yuichiro Anzai, Tokyo)

1. Back ground and summary of the results

A Quartz crystal oscillator[*3] is a device that uses a mechanical resonance to create an electrical signal with high frequency stability. Thanks to its very high frequency purity, it is widely and indispensably used in telecommunication and information processing equipment. However, there is an enormous demand for higher operation frequencies in ever smaller packages in order to develop even faster and more integrated communication networks and infrastructures. NTT laboratories have been engaged in developing new applications for MEMS and its miniaturized counterpart NEMS. In this work, they have applied the operating principle of an optical laser to a micromechanical oscillator and have succeeded in observing a highly stable ultrasonic oscillation. At present, this is a "proof of principle" experiment but could be further miniaturized enabling the development of a higher frequency, and higher precision semiconductor on-chip oscillator than a Quartz crystal oscillator.

2. The oscillator structure

The essential part of the oscillator is a tiny 250-μm long, 85-μm wide, and 1.4-μm thick bar usually called a "beam" (Fig.1). By applying an operating protocol similar to that of an optical laser to this structure, we succeeded in generating an ultrasonic vibration with a frequency fluctuation[*4] that is less than 1 part in 1,000,000. The type of device that generates a highly stable ultrasonic oscillation using similar principle to that of lasers is called a SASER,[*5] in analogy to a laser. The all-electrical operation of the SASER using MEMS was demonstrated for the first time in the world.

3. Technical points

(1) Using the beam structure to play the role of an atom

In an optical laser, a photon is emitted from an atom when it relaxes from a high-energy state to a low-energy one [Fig. 2(a)]. In the newly developed SASER device, the role of the atom can be similarly played by the beam structure itself through the use of a high energy oscillation state and low energy one [Fig. 2(b)].

(2) Precise control of the oscillation states using piezoelectricity

The oscillation states could be electrically optimized by using piezoelectricity[*6] in order to effectively induce the ultrasonic wave. The frequency purity was demonstrated by confirming the generation of a highly frequency-stable output oscillation. In contrast to the frequency fluctuation of 70 Hz in the input oscillation, the fluctuation in the output oscillation was only 80 mHz, being only one part in 2,000,000 of the oscillation frequency (Fig. 3). In addition, the output oscillation was only observed when the input voltage was larger than a specific value, that is, it showed the so called threshold characteristic commonly observed in optical lasers. These observations proved that a similar operating principle to that of laser was realized in the ultrasonic vibration using the beam structure.

4. Future developments

In this experiment, operation with a similar stability in the oscillation to that of a Quartz crystal oscillator was confirmed at low temperature (2.0K) at a frequency of 174 kHz. We plan to further miniaturize and optimize this structure and use more suitable materials in order to realize operation frequencies higher than 1 GHz at room temperature.

Glossary

*1 laser (Light Amplification by Stimulated Emission of Radiation)

Laser is a device that spontaneously generates high purity light utilizing the amplification properties of stimulated emission of radiation. Usually, lasers are composed from atomic gasses or semiconductor crystals that have at least two different energy states that are placed inside a light confinement structure, referred to as a “cavity”. In our SASER device, two oscillation states were used instead of two electronic states, which were confined within the beam enabling the beam structure to play the same role of laser.

*2 Micromelectroechanical systems (MEMS)

Applying the microfabrication technology used for making semiconductor integrated circuits, novel fine structure devices functionalized for tiny motions have recently been developed. These devices when combined with electrical functions are referred to as “microelectromechnical systems (MEMS)”. When these devices are further miniaturized down to the nanometer scale, they are called “nanoelectromechanical systems (NEMS)”.

*3 Quartz crystal oscillator

A device which can generate a highly precise oscillating voltage by using the mechanical resonance of a small Quartz crystal plate. It is used in many electronic systems such as clocks and computers, and is at the heart of the technology that has led to development of our modern sophisticated information-technology society.

*4 Frequency fluctuation

The number of oscillations per second is referred to as an oscillation frequency. The frequency fluctuation is a random variation in its value. For example, the fluctuation of one in one 2,000,000th for 100 kHz oscillation means the frequency can vary between 99999.95 Hz and 100000.05 Hz. Precise oscillators have very small frequency fluctuations.

*5 SASER (Sound Amplification by Stimulated Emission of Radiation)

SASER is a device that spontaneously generates high purity sound utilizing a principle analogous to an optical laser. The concept of a SASER is described in the news article published in the following page of Nature.
’Sasers’ set to stun -- Sound-based lasers could improve imaging and electronics --
Nature News (26 February 2010) | doi:10.1038/news.2010.92

*6 Piezoelectricity

When voltage is applied to a special type of material, it can induce a mechanical expansion or a compression. This phenomenon is called piezoelectricity. In this result, we succeeded in generating and controlling the ultrasonic vibration by using piezoelectricity.

Attachment·Reference

- Fig.1: Device structure
- Fig.2: The mechanism to generate highly stable ultrasonic oscillation
- Fig.3: The frequency spectrum generated by the SASER

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