Field:

Physics/Astrophysics/Astronomy

Session Topic:

Quantum Effects of Motion

Speaker:

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1. Introduction

The "swing" is one of the most familiar playground toys for children but the way to induce its motion is different to that of a simple forced pendulum and it results in rich and interesting physics. The child driving the swing is not applying force in the direction of motion, but simply pushes the seat down, along the perpendicular direction. This action corresponds to a modulation in the distance between the fulcrum and the center of mass which leads to a change in the resonance frequency of the swing. This dynamical system is called as a "parametric oscillator", and has been known from the era of Newtonian classical mechanics. This dynamical system has recently attracted much attention for new application ranging from energy-efficient computer systems to the study of quantum behavior of macroscopic objects. In this talk I will present our results concerning a very tiny "swing" fabricated on a 1-mm-square semiconductor chip, and discuss its basic physics and future applications.

2. The structure and basic operation

In reality, the structure does not have the same shape as the swing, but looks instead like a simple "bar", technically called a "beam", both sides of which are fixed to the chip underneath [Fig.1]. As you can easily imagine from a musical instrument like the "xylophone", the beam vibrates at a fixed tone, i.e., more exactly saying, at the resonance frequency. In the case of a xylophone, the frequency ranges from 100 Hz to 10 kHz at most, but those of our beams are higher than 100 kHz, much faster than a xylophone and needless to say than a child's swing. Figure 2 schematically shows the basic operation of the beam as a parametric oscillator. The bar can be pushed not in the vibration direction but in the direction perpendicular to this. This driving force is similar to that given by the child in the case of the swing and it changes the resonance frequency of the beam. This periodic change gives rise to an oscillatory motion in the perpendicular direction, which is called a parametric oscillation.

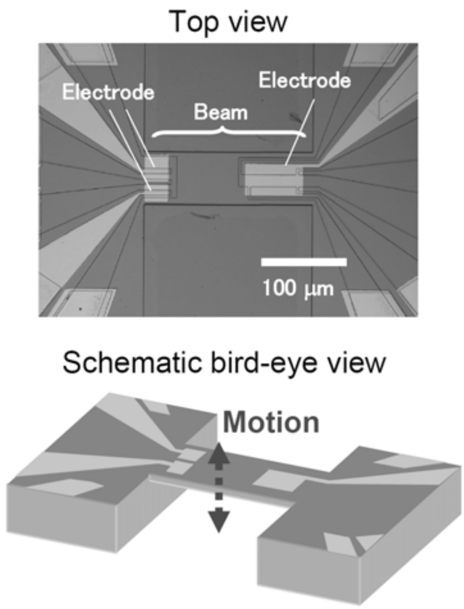

Fig.1 An optical microscope image and the schematic bird-eye view of the parametric oscillator.

In our real device, we can not apply such a force by our hands; instead it is applied via an electric voltage which changes the resonance frequency of the beam.

3. Application for novel computer systems.

One of the most interesting features of parametric resonators is bistability. Figure 2 shows the two possible motions induced by the above periodic force. These two motions are basically identical, but one is delayed by a half period from the other. Both oscillations are equally likely to be excited and they can be distinguished by measuring the oscillating voltage generated. In light of this, a very challenging idea was proposed which uses the bistability in the parametric oscillator to make a programmable computer [1]. This system was first made using parametric oscillators not in the form of beams but from electrical circuits and was called the "parametron". Practical computer systems with more than several thousand electrical parametric oscillators were fabricated about 50 years ago. This lead to the development of real computational architectures and practical software consequently, it is now straightforward to replace the electrical circuits by our tiny mechanical "swing" by using a state-of-the-art nanotechnology. We have demonstrated the basic operation of parametron using the beam oscillator [2]. Although it is not easy to replace the present state-of-the-art LSI technology, the energy consumption of the nanomechanical parametron computer is expected to be very small.

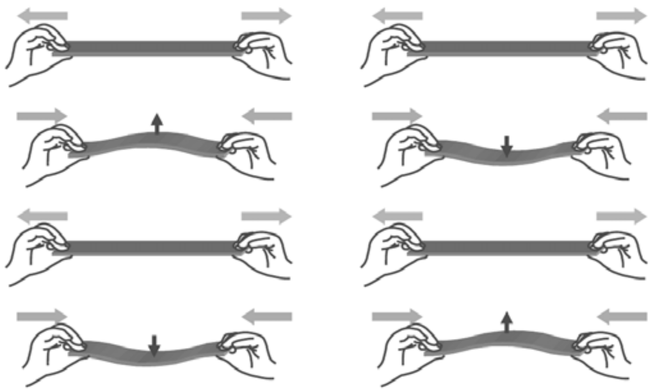

Fig. 2 Schematic illustration of two stable oscillational states in the parametric oscillator.

4.. Application for the study of quantum behavior of macroscopic objects

Recently, some theoretical works have discussed the use of the bistability in parametric oscillators for the study of quantum mechanical properties in macroscopic objects [3]. In Newtonian mechanics, these two oscillation states are perfectly stable at sufficiently low temperatures, but it is not the case in the world of quantum mechanics; where the sudden switch from one state to the other can occur by quantum effects. Although the beam is very small, we call it a macroscopic object because it consists of millions of atoms. There are many interesting discussions concerning quantum behavior of macroscopic objects like Schrödinger's cat, and the experimental implementation of such thought experiments is one of the most fascinating targets in the field of fundamental physics.

References

[1] E. Goto, Proc. IRE 47, 1304 (1959).

[2] I. Mahboob and H. Yamaguchi, Nature Nanotechnol. 3, 275 (2008).

[3] For example, M. Marthaler and M. I. Dykman, Phys. Rev. A 76, 010102(R), (2007).