A novel scanning Thermal Microscopy System

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journal or publication title	IEEE 20th International Conference on Micro Electro Mechanical Systems, 2007. MEMS
volume	2007
page range	627-630
year	2007
URL	http://hdl.handle.net/10097/46612

doi: 10.1109/MEMSYS.2007.4433123

A NOVEL SCANNING THERMAL MICROSCOPY SYSTEM

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ABSTRACT

This paper describes a concept, fabrication and evaluation of a novel nano-meter scale Scanning Thermal Microscopy (SThM) system. The purpose of this research is a realization of a non contact type SThM system. A measurement probe in our system consists of a pyroelectoric detector and an infrared ray shielding film with an aperture for high lateral resolution. It is shown that the first results of the pyroelectric detector (PZT) and the shielding film with an aperture were successfully fabricated.

INTRODUCTION

The invention of scanning tunneling microscope (STM) [1] and atomic force microscope (AFM) [2] have accelerated progress of science and engineering in nano, micro and mesoscopic ranges. Many other scanning probe microscopes including thermal followed the invention [3],[4].

Thermal property of thin films and micro structures are becoming more and more important in a wide range of technical applications and basic science. Especially, developments and operations of optical phase change discs, microelectronic devices and micro energy devices should be based on thermal property as well as each own function characteristics, mechanical property, and so on.

Scanning thermal microscopy (SThM) is expected to be an effective tool for improving the resolution in temperature and energy dissipation measurements. However, because the contacted thermocouple or heated probe tip scans the specimen surface, the resolution is not high, and the dissipation of energy is caused. For instance SThM of thermocouple, semiconductor diode, metallic resistor, and thermistor usually show lateral resolution of several hundreds nm. These kinds of SThM have a problem of an influence against a specimen. The purpose of this research is a realization of a non contact and high resolution type SThM system with low influence against a specimen by using pyroeletric detector with insulation film having a minute aperture.

CONCEPT

To achieve simultaneous topographical and thermographical imaging on nanometer scale, the AFM technique was applied to our SThM system. The tip-to-force is used as feedback to keep the distance between a measurement probe and a specimen. At the end of AFM cantilever, a pyroelectric film is formed as a detector.

Figure1 shows the concept of the novel SThM system. This system has a measurement probe that consists of a pyroelectric detector onto a micro cantilever and an infrared ray shielding board with a minute aperture.

A principle of the temperature measurement is on the basis of the detection the thermal infrared radiation by using the pyroelectric films onto the cantilever. The infrared ray intensity that depends on the sample surface temperature is measured by the pyroelectric detector of a PZT film. Temperature measurement in the nano-scale area is achieved by limiting the infrared ray with the nano-scale aperture for near field optics.

The minute aperture having several tens nm in diameter has achieved as in the way proposed by one of the authors [5],[6] to be applied for near field optics. Our system can be expected to realize a high resolution SThM to measure nano-scale area temperature.

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MEMS 2007, Kobe, Japan, 21-25 January 2007.

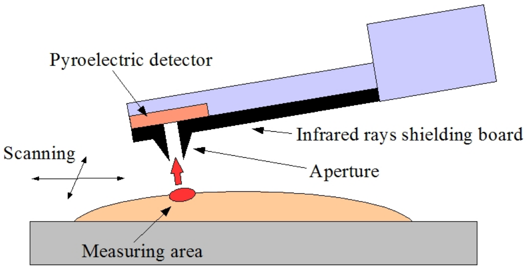

Figure 1. Schematic diagram of a novel scanning thermal microscopy (SThM).

FABRICATION PROCESS

A fabrication process of the cantilever with the pyroelectric detector is shown in Fig. 2. The detector onto a SiO_2 and a nano-scale aperture onto a Si cantilever were fabricated using Si wafers independently. Finally the detective cantilever and the Si cantilever having the minute aperture are bonded. In Fig.2, a SiO_2 film of 850 nm in thickness was formed by wet thermal oxidation on a Si (100) wafer at 1100 ℃. After the SiO_2 film patterned a Pt/Ti bottom electrode film of 350 nm in thickness was deposited by sputtering using Ar gas of 2 Pa at room temperature. A Titanium film contributes an improvement in bonding between a Platinum film and a SiO_2 film. A Platinum film which lattice constant is similar to PZT also contributes a PZT (111) orientation growth.

A PZT film of about 500 nm in thickness was deposited by magnetron sputtering onto the Pt/Ti film. The depositions were usually applied by 100 RF power using Ar and O_2 gas mixture of $6.7x10^{-1}$ Pa. The PZT film was chosen as pyroelectric material because of its high pyroelectric coefficient. These PZT films were evaluated by using X-ray diffraction (XRD).

A Ni (or Au/Cr) top electrode of 350 nm in thickness was deposited by thermal evaporation (or sputtering) onto the PZT film. Then the film was patterned using lift-off process. After these electrode films patterned, the Si substrate was etched by Reactive Ion Etching (RIE) to form the detective cantilever.

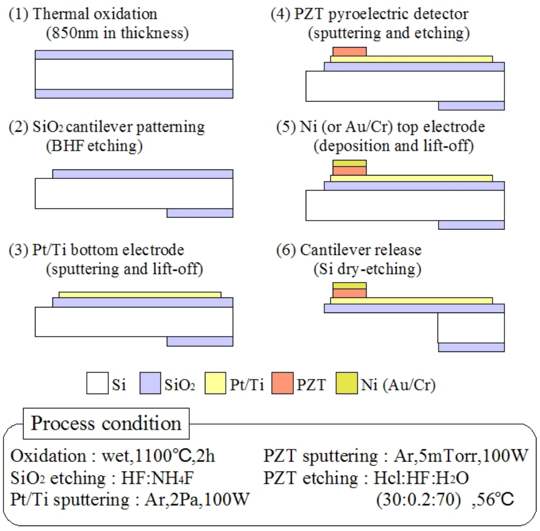

Figure 2. Fabrication process of a PZT detector.

Some important conditions of PZT film formations were substrate temperature, sputtering gas as well as annealing after deposition. The substrate temperature was chosen among 50, 315, and 500 ℃. The sputtering gas was chosen Ar, or Ar/O_2 gas mixture. After the deposition the film was applied by rapid thermal annealing (RTA) using infrared rays. The XRD pattern of the PZT film deposited onto the SiO_2 cantilever was shown in Fig. 3. The peak of PZT(111) was grown by rapid thermal annealing at 680℃ for 10 minutes.

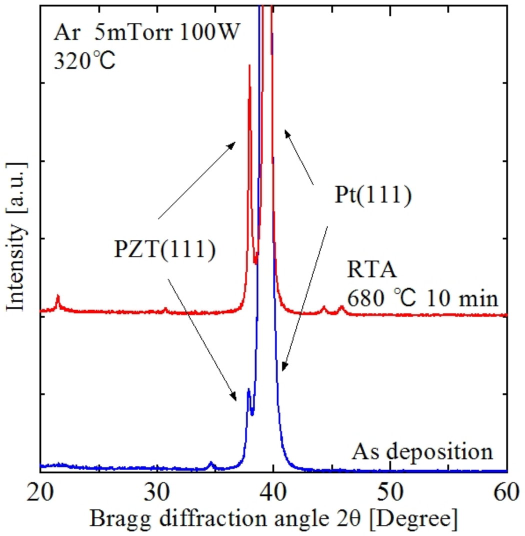

Figure 3. The XRD pattern of the PZT film deposited onto the SiO_2 cantilever.

The substrate temperature of 315 ℃ and the Ar/O_2 gas mixture rate of 1/2 were the best conditions respectively from a point of view of PZT (111) growth.

The photograph of the PZT detector onto SiO_2 cantilever was shown in Fig, 4. Figure 5 shows a ferroelectric hysteresis characteristic of the PZT pyroelecric detector. Pyroelectric current of the detector having 80μm x100μm area onto the SiO_2 cantilever was successfully measured as shown in Fig.6.

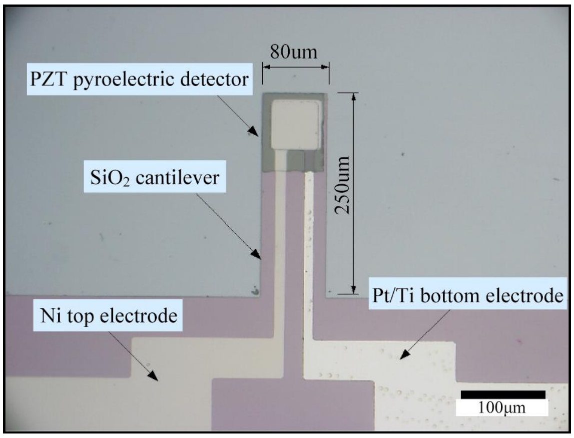

Figure 4. PZT detector onto a SiO_2 cantilever.

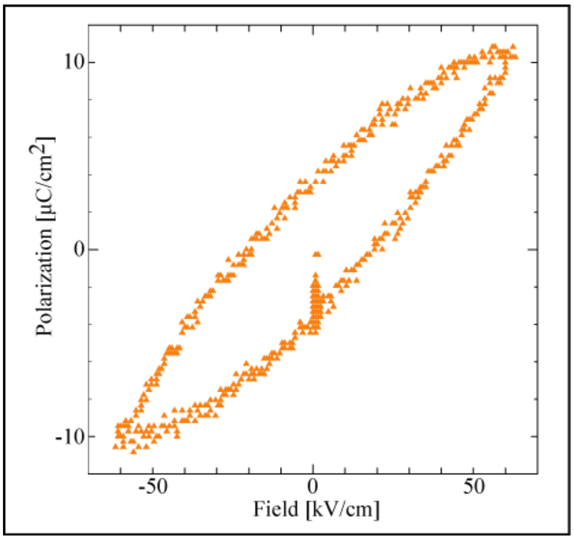

Figure 5. Ferroelectric hysteresis characteristics of the pyroelecric detector.

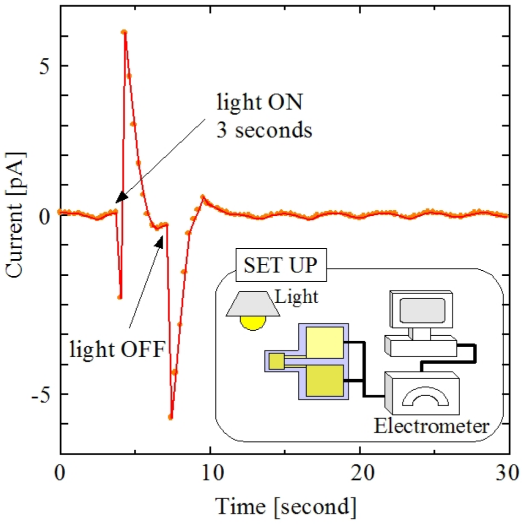

Figure 6. Experimental result of the pyroelectric current.

Pyroelectric current is expressed as follows.

$$i_p = A\left(\frac{dP_S}{dt}\right) = A\left(\frac{dP_S}{dT}\right)\left(\frac{dT}{dt}\right) = Ap\left(\frac{dT}{dt}\right)$$

Where i_p is pyroelectric current, P_S is spontaneous polarization, T is absolute temperature, t is time, A is cross section of electrode, p is pyroelectric coefficient. Figure 6 shows the pyroelectric current characteristics well.

The resolution of the SThM system is determined by infrared ray paths thorough an aperture onto an infrared shielding film. So, a nano-scale aperture is necessary for achieving high resolutions. Figure 7 shows the fabrication process of the miniature aperture applying nonuniform oxidation effect at the pyramidal etched pit. The aperture having several 10s nm in diameter has achieved as in the way proposed by one of the authors. Figure 8 shows a scanning electron microscopy (SEM) photograph of a minute aperture fabricated by the process shown in Fig. 7.

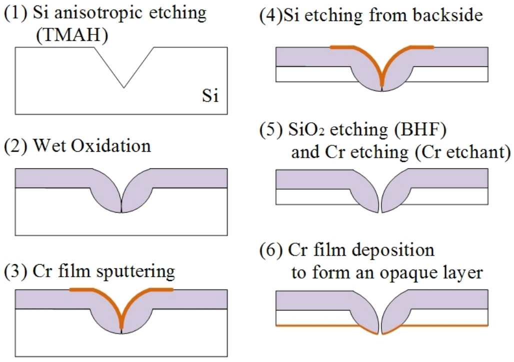

Figure 7. Fabrication process of a miniature aperture.

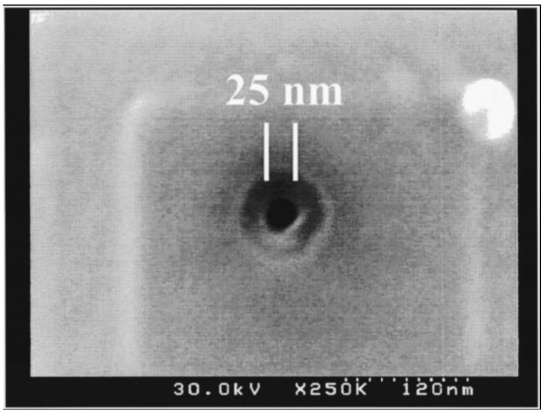

Figure 8. SEM photograph of a minute aperture fabricated by the process as shown in Fig.7.

Another process for fabricating a minute aperture was studied by using a focused ion beam (FIB). Infrared shielding of SiO_2 and Cr were etched by a focused Ga ion beam with 30 keV in energy to make apertures having several diameters from 20 nm to 10 µm. Since electric noise caused by surroundings was not solved in the system, lateral resolution was not defined.

SUMMARY

A novel non-contact scanning thermal microscopy system using pyroelectric detective cantilever was proposed. The concept, fabrication and evaluation were described. A PZT film as a pyroelectric detector onto a SiO_2 cantilever was successfully fabricated and evaluated to find pyroelectric characteristics. Two kinds of fabrication process, namely applying non-uniform oxidation effect as well as a focused Ga ion beam for a minute aperture onto an infrared ray shielding film were studied. Surrounding electric noise was not solved to prevent a high lateral resolution.

ACKNOWLEDMENT

The authors thank Mr. Y. Kawai for his help in the PZT film deposition process. This work was supported through the Creative Scientific Research Program (No. 18GS0203) by the Ministry of Education, Science, Culture and Sports (MEXT).

REFERENCE

[1] G.Binning, H. Rohrer, Ch. Gerber, E. Weibel, Phys. Rev. Lett. 49, 57 (1982).

[2] G, Binnig, C.F. Quate, Ch. Gerber, Phys. Rev. Lett. 56, 930 (1986).

[3] C.C.Williams and H.K.Wickramasinghe, Appl. Phys. Lett. 49, 1587(1986).

[4] Wen-Mei LIN, Renhard KOEHLER, Gunnar SUCHANECK and Gerald GERLACH, Jpn. J. Appl. Phys., 41, 7239(2002).

Phan Ngoc Minh, Takahito Ono, and Masayoshi Esashi, Appl. Phys. Lett. 75, 4076(1999).

[5] Phan Ngoc Minh, Takahito Ono, Masayoshi Esashi, Sensors and Actuators, 80, 163(2000).