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Piezo-thermal probe array for high throughput applications

Angelo Gaitas [a,b,*], Paddy French [b]

[a] PicoCal, Inc., 333 Parkland Plaza, Ann Arbor, MI 48103, USA
[b] EI-EWI, Delft University of Technology, Mekelweg 4, 2628CD Delft, The Netherlands

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ABSTRACT

Microcantilevers are used in a number of applications including atomic-force microscopy (AFM). In this work, deflection-sensing elements along with heating elements are integrated onto micromachined cantilever arrays to increase sensitivity, and reduce complexity and cost. An array of probes with 5–10 nm gold ultrathin film sensors on silicon substrates for high throughput scanning probe microscopy is developed. The deflection sensitivity is 0.2 ppm/nm. Plots of the change in resistance of the sensing element with displacement are used to calibrate the probes and determine probe contact with the substrate. Topographical scans demonstrate high throughput and nanometer resolution. The heating elements are calibrated and the thermal coefficient of resistance (TCR) is 655 ppm/K. The melting temperature of a material is measured by locally heating the material with the heating element of the cantilever while monitoring the bending with the deflection sensing element. The melting point value measured with this method is in close agreement with the reported value in literature.

1. Introduction

Microcantilevers are used in a number of applications including atomic-force microscopy (AFM) [1]. Deflection-sensing elements are integrated onto micromachined cantilevers to increase sensitivity, and reduce complexity and cost. These sensing elements are made by selectively doping silicon [2,3], or by depositing metal or metal oxide films on cantilevers such as gold [4,5]. Compared with doped-silicon sensing elements, deposited metal film elements have certain advantages including simplified fabrication, a lower manufacturing cost, and the capability to scale down to smaller dimensions while maintaining sensitivities and exhibiting lower noise. Metallic sensing elements enable the use of alternative substrate materials (such as polymers), that tend to exhibit higher compliance properties and improved thermal isolation. We have already used polymer cantilevers for explosive detection [6], patch clamping [7], scanning thermal microscopy [8,9], and elastography measurements [7,9]. Thin metal film sensing elements with thickness less than 10 nm have increased piezoresistive sensitivity [10]. Microcantilevers with metal film elements have been used as microheaters [11] and for scanning thermal microscopy [12]. Ultrathin metal films exhibit higher TCR [13].

Using metal sensors is relatively simple to expand to a one or two dimensional probe array for higher throughput multi-location measurements overcoming AFMs throughput limitations. Higher throughput is very important in many applications ranging from semiconductor failure analysis and production applications (where entire wafers or large areas need to be examined in relatively short time), to biological applications such as cell elastography [14] and high throughput patch clamping. Nanofabrication and nanotechnology applications that would benefit from a higher throughput multi-probe system include nanoscale imaging, thermo-chemical patterning [15], and nano-CVD [16], nano-indentation, nano-patterning, and dip pen nanolithography [17]. Finally, material characterization techniques that rely on AFM would benefit from faster analysis rates, simultaneous multiple location measurements, and lower costs, some examples include thermo-mechanical and mechanical analysis.

The probe arrays described in this paper include a monolithic integration on each cantilever of a heating element (which can also be used for temperature sensing) and a deflection (or displacement) sensing element. Gold films of 5–10 nm thicknesses were deposited on a silicon cantilever to form both sensing elements. The probes operate without the need of an optical lever required by AFM systems to detect cantilever deflection. In addition, the probes have a very large dynamic range of tens of micron. This paper is an expansion of prior work on single cantilevers with monolithically integrated displacement sensors and micro heaters/thermal sensors for melting point measurements and thermo-mechanical analysis [11], material characterization of mechanical properties [18], and scanning probe microscopy [18].

* Corresponding author at: 333 Parkland Plaza, Ann Arbor, MI 48103, USA. Tel.: +1 734 913 2608; fax: +1 734 619 6676.
E-mail address: angelo@picocal.com (A. Gaitas).

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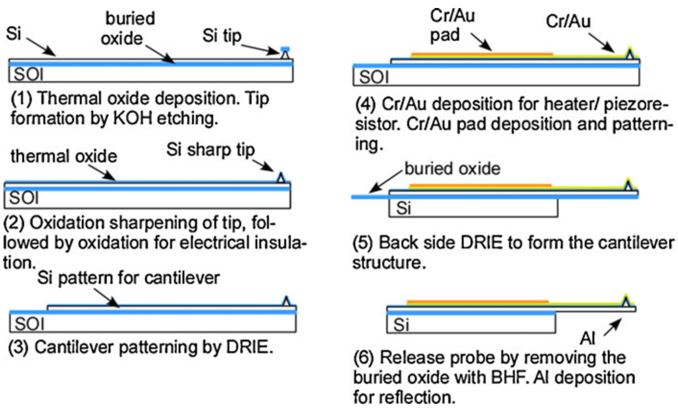

Fig. 1. Process flow for fabricating the probe array.

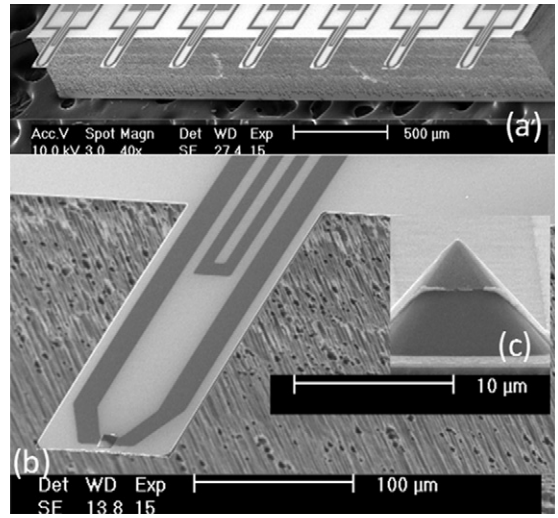

Fig. 2. (a) SEM of the probe array. (b) Individual cantilevers include two resistors, one over the tip serving as a localized heater/thermal sensor and a second closer to the base serving as a resistor for deflection sensing. Inset (c) SEM close-up of the tip.

2. Device and fabrication

The device is fabricated in a process described in Fig. 1 and is similar to the ones reported previously [11,18]. A thermal oxide masking layer is grown and patterned for the probe tip on a silicon-on-insulator (SOI) wafer. The tip is formed using KOH anisotropic etching (Fig. 1(1)), the oxide mask is then removed, and the tip is sharpened with several oxide sharpening steps [19]. The oxide sharpening step involves thermal oxidation followed by hydrogen fluoride (HF) etching repeated at least three times. A 100 nm-thick silicon oxide is thermally grown on the wafer to provide electrical insulation (Fig. 1(2)). The cantilever is patterned on the front side of the wafer with the Bosch deep reactive-ion etching (DRIE) process (Fig. 1(3)). Metal lines are evaporated and patterned on top of the cantilever structure with lift-off process to form the sensing elements (Fig. 1(4)). The thicknesses of the metal layers are measured during the evaporation and the variation is within ±10%. The suspended cantilever is then formed by back side DRIE with an etch rate of 3 μm/min (Fig. 1(5)). The 1 μm buried oxide layer of the SOI wafer acts as an etch stop to prevent the back side DRIE from attacking the Si cantilever structures. Finally, the probes are released by removing the buried oxide layer using buffered HF etchant. If the probe array is used with an AFM, then a thin layer of aluminum is evaporated on the back-side to improve the laser reflection (Fig. 1(6)).

Fig. 2 shows the resulting micro-cantilever array. The design includes two sensing elements on one cantilever, each of which consists of a gold film deposited on a silicon oxide/silicon cantilever. The resistor covering the tip area forms a micro-bolometer (heating element) and a resistor near the base of the cantilever forms a deflection sensing element. The rectangular cantilever is 100 μm wide, 200 μm long, and 2 μm thick. The resulting cone shaped tip has a 100 nm diameter and a 7.5 μm height.

3. Experimental set-up

The experimental set-up is shown in Fig. 3. The change in resistance of the deflection sensing element of the cantilever is directly measured using a micro-Ohm meter (Agilent, HP-34420A), without the need of an interface amplifying circuit. The thermal element is heated using a variable power supply (Keithley 2400). The data are acquired with a LabView program. A piezoelectric XYZ stage with 100 μm range and nanometer resolution on each axis (PiezoJena, Tritor 100) is used to move the sample underneath the probe array. A Zaber motorized stage is used for larger movements is the *XYZ* direction.

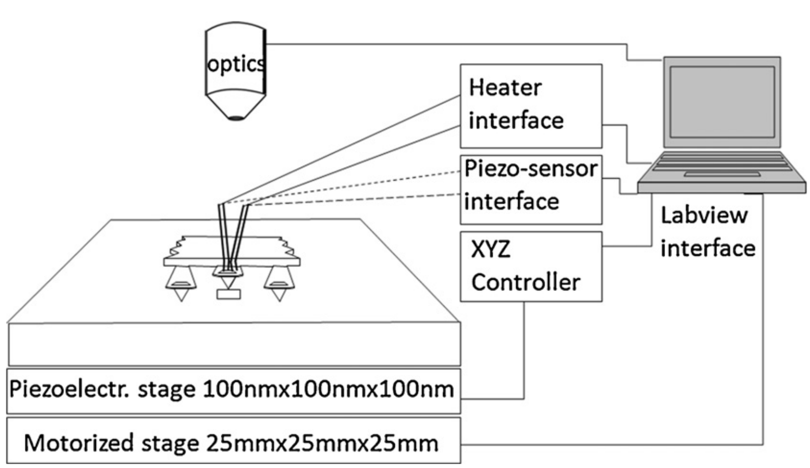

Fig. 3. The experimental set-up used to conduct these studies.