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Elimination of stress-induced curvature in microcantilever infrared focal plane arrays☆

Shusen Huang, Biao Li, Xin Zhang*

Laboratory for Microsystems Technology, Department of Manufacturing Engineering, Boston University, 15 Saint Mary's Street, Boston, MA 02215, USA

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Abstract

This paper reports an approach to eliminating stress-induced curvature in microcantilever-based infrared focal plane arrays (FPAs). Using a combination of argon ion beam machining and rapid thermal annealing (RTA), we successfully modified curvatures of free-standing SiN_x/Al bimaterial FPAs. The SiN_x/Al FPAs were fabricated using a surface micromachining technique with polyimide as a sacrificial material. The as-fabricated FPAs were concavely curved because of the imbalanced residual stresses in the two materials. To modify the FPAs curvature, first, Ar ions with energies of 500 eV was used, which sputter etched PECVD SiN_x at a rate of 4 nm/min, and 20 min of ion beam machining reduced the FPAs curvature from -1.92 to $-0.96\ \mathrm{mm}^{-1}$. Then based on the investigation on the thermomechanical behavior of both the e-beam Al and PECVD SiN_x films during the thermal cycling, RTA was proposed to further modify the FPAs curvature. It is found that 5 min of RTA at 375 °C resulted in flat FPAs with acceptable curvatures ($<0.10\ \mathrm{mm}^{-1}$).

Keywords: Microcantilever infrared focal plane arrays; Residual stress; Curvature; Ion beam machining; Rapid thermal annealing

1. Introduction

Detection and imaging of infrared (IR) radiation is of great importance to a variety of military and civilian applications ranging from night vision to environmental monitoring, biomedical diagnostics, remote sensing, and thermal probing of active microelectronic devices. In particular, the wavelength region from 8 to 14 μm is of importance, not only because atmospheric absorption in these regions is especially low but also because this region contains the peak of the blackbody spectrum for objects around room temperature [1,2].

Recent advances in microelectromechanical systems (MEMS) have led to the development of uncooled microcantilever-based IR detectors (briefly called cantilever IR detectors in this paper), which function based on the bending of bimaterial microcantilevers upon the absorption of IR radiation [3–6]. The micromechanical deformations can readily be determined by a number of means, including piezoresistive, optical, and capacitive. The piezoresistive method is limited by its low sensitivity because the electric current running through the piezoresistors generates heat. Using an optical readout, the devices developed by Zhao et al. [4] and Datskos et al. [5] exhibited NETD values of 200 and 90 mK, respectively. The capacitance measurement detects changes in capacitance between the cantilever and the substrate. Using optical or capacitive sensing technology, cantilever IR detectors have the potential of reaching an NETD approaching the theoretical limit and have gained increasing interest.

Briefly speaking, the released part of a pixel in cantilever IR FPAs is comprised of three components: (i) an absorbing plate that converts IR into heat; (ii) a bimaterial sensing element that converts heat into mechanical deformation; (iii) a thermally isolating support to prevent heat from being shunted down to the substrate. A bimaterial cantilever of SiN_x and Al has been chosen as the thermal sensor because of the large mismatch in their thermal expansion coefficients (CTE) as well as fabrication feasibility [3–6]. However, the released bimaterial cantilevers

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* Corresponding author. Tel.: +1 617 358 2702; fax: +1 617 358 5548.
E-mail address: xinz@bu.edu (X. Zhang).

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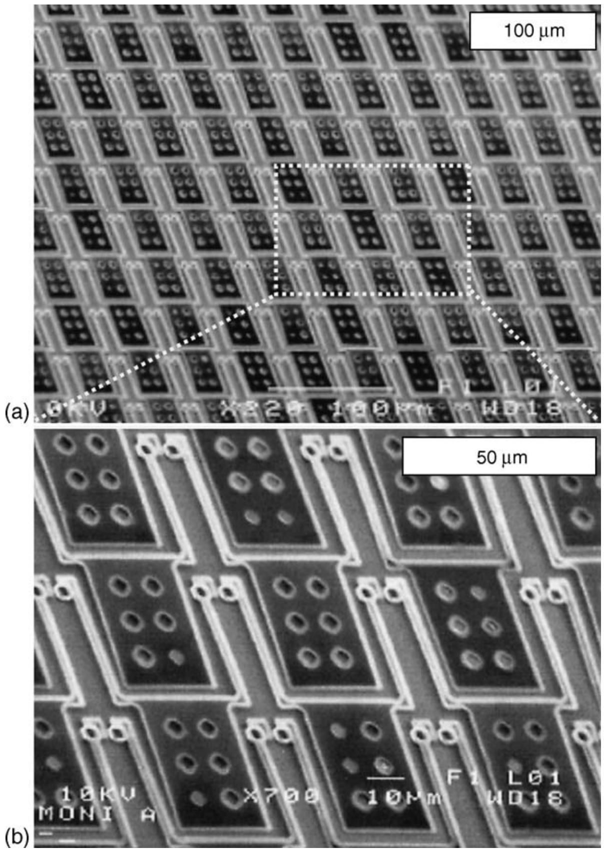

Fig. 1. (a) An SEM image of a part of bimaterial SiN_x/Al cantilever IR FPAs. (b) A close-up view showing that the as-fabricated pixels were concavely curved because of the imbalanced residual stresses in the two materials.

are always curved due to the imbalanced residual stresses in the two materials, as shown in Fig. 1. Cantilever bending has a major influence on the device performance and functionality, and hence its reduction is currently a major research effort. In this paper, we report an approach to eliminating the residual stress-induced curvature of bimaterial SiN_x/Al FPAs. The method we used includes a combination of argon (Ar) ion beam machining and rapid thermal annealing (RTA) treatments. Bimaterial FPAs with an acceptable curvature have been obtained in our proof-of-concept experiments.

2. FPAs fabrication

In this paper, bimaterial SiN_x/Al infrared FPAs were fabricated using a low-temperature surface micromachining technique with a commercial PI2610 polyimide (HD Microelectronics) as a sacrificial layer [7,8]. The use of this spin-on polyimide allowed an all-dry final release step overcoming stiction problems, which are often encountered in wet sacrificial etching processes.

The fabrication process is schematically illustrated in Fig. 2. Polyimide was spun on 4-in. silicon wafers at a spin speed of 2200 rpm for 30 s. The polyimide was then cured on a hotplate at 90 and 150 °C, both for 30 min, followed by further curing in N_2 atmosphere at 350 °C for one hour. The cured polyimide had a thickness of about 2.5 μm, which was designed to form a λ/4 resonant cavity between the cantilever and the substrate to enhance the infrared absorption in the wavelength of 8–12 μm [3–6]. For the patterning of the polyimide, a 500 nm-thick plasma-enhanced chemical vapor deposited (PECVD) SiO_x layer was deposited and then patterned by reactive ion etching (RIE) using a mixture of SF_6 and He [9]. The advantage of using SiO_x as an etching mask is that it is easy to remove the SiO_x in a buffered oxide etcher (BOE) that does not attack the polyimide. The anisotropic etching of the polyimide layer was then accomplished by RIE. In this RIE process an O_2 flow of 40 sccm (standard cubic centimeters per minute), a power of 300 W and a pressure of 100 mTorr were selected, resulting in an etch rate of about 870 nm/min. After the stripping of the SiO_x, a 200 nm-thick Al layer was deposited with a Temescal^{TM} electron beam (e-beam) evaporator at a rate of 0.2 nm/s. Then the deposition of a 200 nm-thick SiN_x layer was carried out with a STS^{TM} PECVD unit at a rate of 0.18 nm/s. The operation parameters for the SiN_x deposition are given in Table 1. The thicknesses of the Al layer and the SiN_x layer were determined to maximize

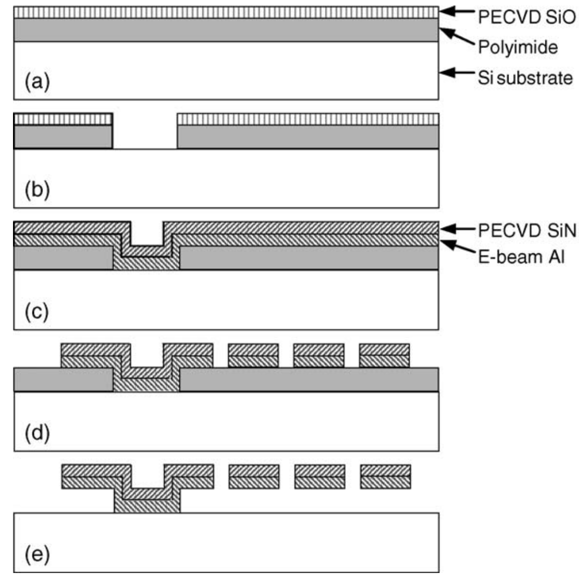

Fig. 2. Process flow for the fabrication of SiN_x/Al cantilever IR FPAs. (a) A 2.5 μm-thick polyimide was spin coated on a Si substrate and cured at 350 °C, followed by the deposition of a 500 nm-thick PECVD SiO_x. (b) The polyimide was patterned by RIE with the SiO_x as the hard mask. (c) After the removal of the SiO_x, a 200 nm-thick e-beam Al and a 200 nm-thick PECVD SiN_x were deposited. (d) The SiN_x was patterned by RIE with a mixture of SF_6 and He, followed by the patterning of the Al by phosphorous acid. (e) The bimaterial SiN_x/Al FPAs were released upon the removal of the sacrificial polyimide.

Table 1
Deposition conditions for PECVD SiN_x films

N_2 flow rate	1960 sccm
NH_3 flow rate	40 sccm
SiH_4 flow rate	55 sccm
rf frequency	13.56 MHz
rf power	20 W
Substrate temperature	300 °C
Total pressure	900 mTorr
SiN_x deposition rate	0.18 nm/s