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Surface-micromachined Ta–Si–N beams for use in micromechanics

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Abstract. Realization and characterization of free-standing surface-microstructures based on Ta–Si–N films are presented. Due to their significant physical and chemical properties, such ternary films are promising candidates for application in microelectromechanical devices.

1. Introduction

Amorphous Ta–Si–N thin films have been proven to successfully meet the requirements for use as diffusion barriers for metal/silicon contacts in microelectronics [1]. In addition, the resistivity of such Ta–Si–N films is a few hundred $\mu\Omega$ cm for nitrogen concentrations less than 50% [2], thus filling the gap between metal conductors and doped polysilicon. Furthermore, the amorphous structure of this new material may hamper fatigue effects as often observed in metals. The fabrication of x-ray amorphous Ta–Si–N microbeams using a sacrificial Al layer has been shown previously [3]. This paper describes an alternative IC-compatible process employing phosphorus-doped silicon dioxide (PSG) as a sacrificial layer. Furthermore, etching characteristics of Ta–Si–N are investigated, i.e., the resistance in wet etchants as well as the patterning by dry etching. Finally, the electromechanical behaviour of Ta–Si–N beams integrated together with substrate diffusions is demonstrated.

2. Experimental details

The Ta–Si–N films have been deposited by reactive sputtering in an Ar/N_2 plasma (5% N_2 partial gas pressure) employing a Ta_5Si_3 target. In order to decrease the compressive stress of the as-deposited films, annealing at 450 °C is carried out [3]. An example of a fabricated free-standing Ta–Si–N microstructure is shown in figure 1. The PSG layers have been produced by chemical vapour deposition (CVD) at 350 °C and densified at 625 °C. A lateral etch rate of about 0.4 μm min^{-1} is achieved for the sacrificial PSG in buffered hydrofluoric acid (BHF 7:1).

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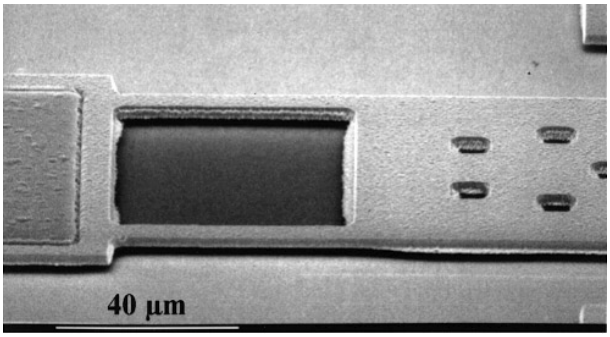

Figure 1. A SEM of a Ta–Si–N microactuator beam structure; the beam is 300 μm long and 80 μm wide. The underetch holes are 10 μm in diameter and the tethers are 20 μm wide.

Table 1. The chemical resistance of Ta–Si–N.

Chemical	Time
BHF [7:1]	more than 60 min
HNO_3 (100%)	at least 10 min
$H_2SO_4 + H_2O_2$	at least 10 min
$H_3PO_4 + HNO_4$ (aluminium etchant)	more than 100 min

As indicated in table 1 etch tests revealed that Ta–Si–N resists BHF (7:1) for more than one hour. This is essential for the sacrificial layer technology where etching times of this order are required. Furthermore, Ta–Si–N successfully withstands wet etching in HNO_3 (100%) and H_2SO_4/H_2O_2, i.e., no thickness reduction or degradation such as strong oxidation was observed. Thus, standard cleaning and resist-stripping steps using the above acid mixtures do not attack Ta–Si–N layers.

The patterning of Ta–Si–N films is usually performed

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Table 2. Ta–Si–N dry etching: process parameters and results.

Gases	C_2ClF_5/SF_6	SF_6/O_2
Mask	positive photoresist	positive photoresist
Pressure (mbar)	0.1	0.2
Power (W)	100	125
Etch rate (nm min^{-1})	70	140

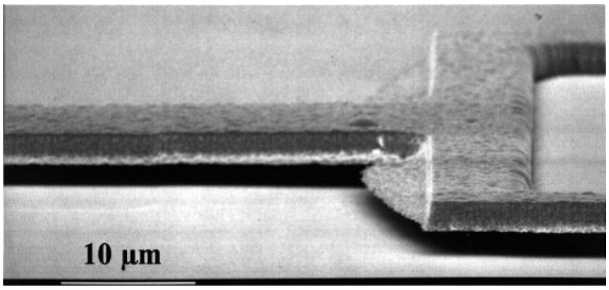

Figure 2. A SEM close-up of the anchor pad (right-hand side) of a 300 μm long and 20 μm wide Ta–Si–N beam actuator.

by dry etching [4]. As shown in table 2, reactive ion etching (RIE) using SF_6/O_2 and C_2ClF_5/SF_6 gases has been applied. The chlorine/fluorine gas mixtures resulted in better uniformity than the fluorine (oxygen) gases. The sidewall profiles of a Ta–Si–N structure as etched in a C_2ClF_5/SF_6 plasma are illustrated in figure 2. The remaining parts at the edges can be suppressed by an appropriate overetching. Choosing appropriate process parameters for power and pressure, etch rates of more than 100 nm min^{-1} are achieved.

3. Application and discussion

By adding substrate diffusions as counter-electrodes under the Ta–Si–N microbeams as sketched in figure 3, electrostatically driven prototype actuators have been built. The transfer function of these devices under vacuum has been measured with an optical interferometer. The output signal of the latter has been fed into a gain-phase analyser. Figure 4 shows the characteristics for such a clamped–clamped beam. Resonance frequencies of 113 kHz and 140 kHz were measured for 350 μm and 300 μm long beams having a thickness of 2 μm. As can also be seen from figure 4, these devices exhibit a relatively high quality factor of about 1000 in vacuum. Thus, the resonance behaviour of the Ta–Si–N structures is promising for application in micromechanical devices such as relays [5]. Compared with polysilicon, the amorphous Ta–Si–N has similar mechanical properties but a higher electrical conductivity. In addition, a comparable lifetime is expected.

4. Conclusion

Free-standing Ta–Si–N microbeams, employing CVD silicon dioxide as sacrificial layer, have been demonstrated.

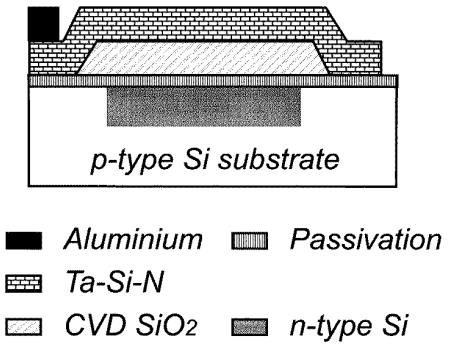

Figure 3. Schematic cross section of a surface micromachined Ta–Si–N actuator with an electrostatic drive. CVD silicon dioxide serves as the sacrificial layer.

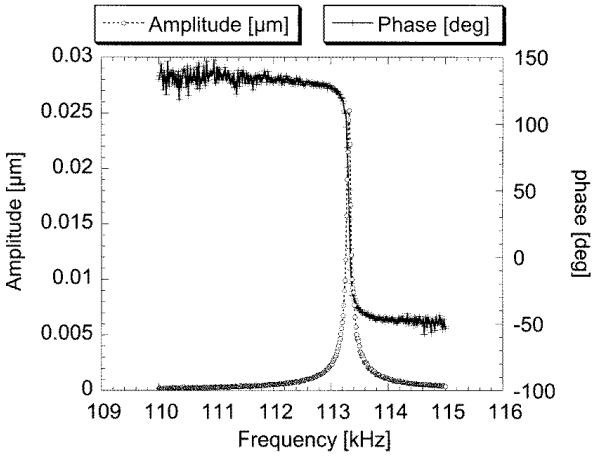

Figure 4. Measured transfer characteristic of a 350 μm long beam actuator in vacuum; the resonance frequency reveals a quality factor of about 1000.

The outstanding physical properties of the Ta–Si–N structures point out the attractiveness of this material for use in microelectromechanical components such as resonators or switches. Moreover, the resistance of Ta–Si–N to chemicals allows for application in an aggressive environment. Future work will focus on the mechanical property characterization.

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