Amorphous Metals as New Materials for Transducer Applications

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Introduction

Appropriate physical and chemical characteristics as well as reproducibility and long-term stability of new materials are sustantial for their use in microsystems. Amorphous TaSiN thin films have proven to successfully meet the requirements as diffusion barriers for metal/silicon contacts in micro-electronics [1]. They are thermodynamically stable with their adjacent materials (Al, Cu, Si or silicide) and, due to their lack of grain boundaries, show a satisfactory opaqueness for metals. Moreover, the resistivity of these TaSiN films is a few hundred μΩ cm for nitrogen concentrations less than 50%, representing adequate electrical conductivity [1]. In terms of mechanical properties, a Young's modulus of 190 GPa has been measured for the TaSiN films [2] which is of the order of that of silicon. Furthermore, compressive stress in the 100 MPa range of the as-deposited films could be reduced by annealing: heating up to 450°C resulted in a monotonic stress decrease and subsequent recooling even reversed into the tensile direction [2]. Finally, the amorphous microstructure of this new material may impede fatigue and wear effects, as often observed in metals. Considering all these outstanding material properties, amorphous TaSiN films are promising candidates for application in micro-electromechanical devices. By adding Al as a sacrificial layer, the fabrication of freestanding TaSiN surface microstructures was achieved.

Sputter Deposition and Film Properties

The amorphous TaSiN films were deposited by reactive sputtering in an Ar/N_2 plasma with a total gas pressure of 10^{-2} mbar. A Ta_5Si_3 target was employed and sputtering was performed by applying a DC power of 800 W. Compared with the RF mode, the DC sputtering resulted in a higher deposition rate of about 10 nm/min·kW.

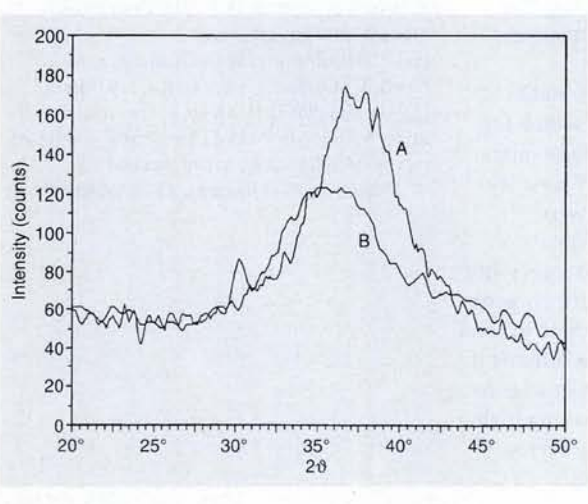

Fig.1. X-ray diffraction pattern of TaSiN films sputter-deposited at different partial gas pressure ratios of N_2 to Ar: A – 5% N_2; B – 10% N_2

No extern heating was applied. The substrates were exposed to the plasma induced heating at around 100°C. An *in situ* pre-etch in an Ar/O_2 plasma significantly improved the adhesion of the films.

In our investigation we also applied a new physical measurement system for micro-electromechanical devices, called the X-ray rocking curve method, which allows the strain in a crystal to be measured. With high-resolution instruments (high-resolution X-ray diffractometer, HRXRD) a strain tensor profile can be rec-orded and thus a detailed surface strain analysis is possible [3]. Strain on the wafer induced by amorphous TaSiN layers can be documented. HRXRD is a non-destructive method with a high strain sensitivity. By using Hooke's law, the stress can be determined from the lattice strain. HRXRD measurements were performed to investigate the substrate strain induced by the metal layer using the very intense beam of a MPD1880/HR-Philips diffractometer with a Bartels monochromator. We have a powerful method for the investigation of thin films up to the order of some μm, the typical range of micromachined actuators.

Crystallinity analysis was carried out using a Philips PW1050 computer-controlled X-ray diffractometer with filtered CuKα radiation. X-ray diffraction patterns of the TaSiN films deposited at different N_2 partial pressures are illustrated in Fig. 1. Pattern A is obtained from a sample with 5% N_2 and pattern B from a sample with 10% N_2, where the percentage refers to the partial gas pressure ratio of N_2 to Ar in the sputtering process. To obtain a well-defined background signal, all measurements were performed onTaSiN films deposited on [100] Si wafers. It is clearly seen that both samples are X-ray amorphous, although the maximum is shifted, between 5% and 10% N_2. Cross-sectional TEM measurements revealed [2] that this is also the range where the change from amorphous to crystalline occurs. RBS measurements of these TaSiN films yielded the following atomic compositions (with an error of about 10%) of $Ta_{49}Si1_4N_{37}$ for 5% N_2 and $Ta_{44}Si_{14}N_{42}$ for 10% N_2. The crystallisation temperature of the TaSiN films as determined by X-ray diffraction was about 800 °C (about an hour), representing a high thermal stability.

A contact AFM picture of a sputtered TaSiN surface is shown in Fig.2; it was taken by an AutoProbe LS Scanning Probe

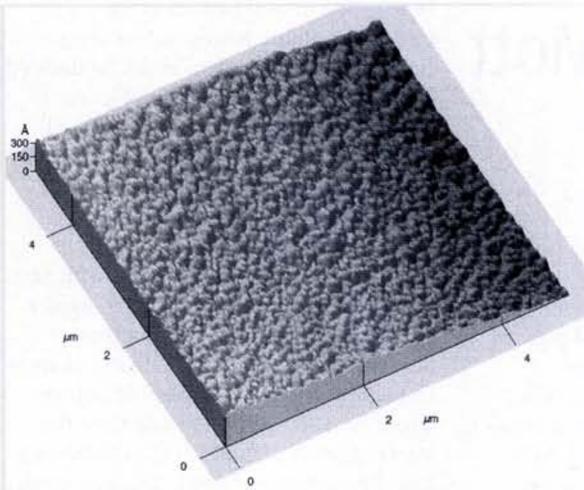

Fig. 2. Contact AFM image of a section of sputtered TaSiN surface

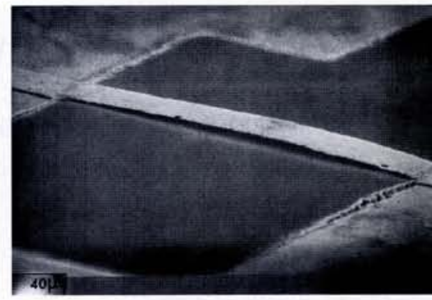

Fig.3. SEM of a free-standing amorphous TaSiN microbridge with Al as the sacrificial layer

Microscope by Park Scientific Instruments with an 0.6 µm microlever.

The surface is extremely smooth, having a roughness of less than 20 nm. Thus, amorphous TaSiN films are promising candidates for micromechanics applications requiring low friction. Preliminary friction measurements between two coated samples revealed smaller values than in the case of steel.

Surface-Micromachined TaSiN Structures

Sacrificial layer technology has become a well-established surface micromachining technique for the fabrication of three-dimensional microstructures from thin films on any process-compatible substrate. An all-metal combination has been chosen for the fabrication of free-standing amorphous TaSiN films (1–2 µm thick) with Al (2–4 µm) as a suitable sacrificial layer. In particular, both layers can be sputter deposited in a low temperature step (less than 300 °C), offering the possibility for post-processing on a substrate with prefabricated electronic components. The patterning of the TaSiN was performed in a SF_6/O_2 plasma using a photoresist mask; further fluorine-based dry etching processes are described in [4], for example. The lateral etching of the sacrificial Al in a standard H_3PO_4/NHO_3 mixture was highly selective, i.e. the etchant did not attack the TaSiN film.

A fabricated TaSiN microbridge is shown in Fig. 3. The slight buckling of the free-standing double-clamped beam indicates that the compressive stress of the TaSiN film was in agreement with the measurements by Reid [2]. This compressive stress in the 100 MPa range was reduced by heating up to 450 °C.

Potential applications for such amorphous metal microbridges are switching devices such as micromechanical relays [5]. Compared with polysilicon, TaSiN exhibits similar mechanical properties, the same or a longer lifetime and better electrical conductivity, which satisfies the requirements for a contact material.

References

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