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A taper angle control technique using thin-film layer stiction phenomenon

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ABSTRACT

We propose a simple taper angle control technique which can be easily achieved by using conventional thin-film deposition and wet etching processes. Based on the proposed technique, the taper angle can be controlled below 30° by varying the thickness of the shade layer which will support the top layer by means of the thin-film stiction phenomenon. By applying the proposed technique to the thin-film line resistor structure, we can confirm that variations of the resistance and the heat generation of the thin-film line formed cross the shade structured multiple thin-film line bumps can be suppressed below 6%, while those of the line resistor formed over multiple line bumps without the shade layer are increased by 54.5% and 246.6%, respectively.

1. Introduction

In current complementary metal oxide semiconductor and thin-film transistor technologies, devices and circuits are generally fabricated with multilayer-stacked structures on a large-scaled substrate. In these structures, the planarization process is essential due to the steeply etched thin film patterns in the etching process and the low step coverage issue in the physical vapor deposition, which could aggravate mechanical–electrical reliabilities as well as increase the probability of line disconnections and difficulties in the photolithography process. So far chemical mechanical polishing (CMP) has been considered a simple and effective method for the planarization to be used in the mass production [1,2]. However, it generally involves a high process cost, and is very hard to be applied to a large-scaled flat panel displays. Instead, various tapered etching techniques which can control a taper angle of thin film patterns have been developed so far as an alternative method to CMP such as bilayer [3–7], etching temperature variation [8,9], grain size variation [10,11], etc. However, bilayer method requires etch-selective materials having different etch rate for the same etchant in order to form a gradual taper profile, which limits the selection of materials. The temperature variation and the grain size variation methods need a specially modified fabrication system such as a rapid and precise temperature controllable wet etch bath and a reactive sputtering with Neon gas, respectively, resulting in the increase of fabrication cost and complexity.

In this paper, we propose a simple taper angle control technique using a cantilevered shade structure based on stiction phenomenon to achieve a low tapered angle for the planarization. By constructing the proposed structure with the conventional photo-lithography process, we show that the taper angle of the multi-stacking layers can be easily controlled without involving any complicated fabrication parameters such as deposition and etching temperature and composition ratio of etchant. Furthermore, when we apply this technique to the multi-film stacked structure, the increase of the line resistance and heat generation caused from the thin film formation by the steep taper profile can be greatly suppressed as much as the single film structure patterned on the flat surface.

2. Design and experimental details

Fig. 1 depicts the cross section of our proposed structures having thickness of bottom layer h and shade layer t, and shade length s^* (the width of micro cavity formed by the deflection of the shade layer). The shade layer is patterned by the conventional photo-lithography, and the cantilevered shade structure can be easily obtained by over-etching the bottom layer. However, this floating part of the shade layer was immediately stuck to the substrate after the etch process to form a micro cavity with a certain taper angle. This stiction phenomenon is caused by the interaction between restoring force of the shade layer and attractive force caused by interfacial surface energy originating from a huge surface-to-volume ratio as the feature size shrinks from the millimeter to micro/nanometer scale. This phenomenon is regarded as one of the critical failures in common micro-electro-mechanical systems (MEMS) because sticked microstructures cannot be separated easily by a simple method [12–14]. However, in this paper, we propose to employ this stiction phenomenon to control a taper angle of thin film.

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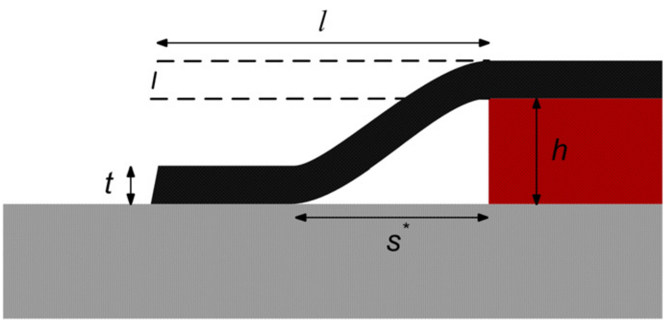

Fig. 1. The cross sectional schematic diagram of the shade structure using thin-film stiction phenomenon.

2.1. Sample preparation

2.1.1. Shade structure

Fig. 2 shows schematic cross-section views of the process steps for the shade structure fabricated by the conventional photolithography technique. The detailed process steps are described as follows. At first, silicon wafer was cleaned in acetone and isopropyl alcohol with a sonicator, and dried with nitrogen. Then adhesion layer (Ti, 500 Å), bottom layer (Mo, 3000 Å), and shade layer (Ti, 50–900 Å) were deposited sequentially by using a DC magnetron sputtering with the base pressure of 5.3×10^{-4} Pa and a working pressure of 0.67 Pa in Argon environment (Fig. 2(a)). Secondly, the shade layer and the bottom layer were patterned by a single process of conventional photolithography using positive photoresist as shown in Fig. 2(b). To protect a thin shade layer during the fabrication, wet etching by dipping was performed, and the substrate was dried by the spinner instead of using an air gun. Shade layer was etched in 30% diluted sulfuric acid at 60 °C, followed by etching the bottom layer in phosphoric-acetic-nitric (PAN) acid (180 phosphoric acid, 11 acetic acid, 11 nitric acid and 180 deionized water) at 40 °C using the shade layer as the mask. Since both sides of the bottom layer were not protected by the shade layer, they were easily over-etched by PAN acid as shown in Fig. 2(c) and (d), resulting in the cantilevered shade layer floating in the air. The pattern of the photoresist above the shade layer was maintained during the fabrication so that any possible residue of PAN acid captured under the overhang of the shade layer can be easily washed away by the DI water. Once the photoresist above the shade layer was stripped off, this floating part of the shade layer was immediately collapsed to the substrate by the capillary and electro-static force to form the micro cavity structure as shown in Fig. 2(d) and (e), so that it could prevent further inflow of the etchant to both sides of the over-etched bottom layer. Finally, the proposed shade structure of which taper angle was controlled by the stiction phenomenon was completed as shown in Fig. 2(f) after conventional cleaning and spin-drying processes followed by the annealing on the hot plate for eliminating any liquid remaining in the micro-cavity.

2.1.2. Line resistor patterns over the crossed metal lines

In order to confirm the thickness uniformity of the thin-film pattern above the proposed shade structure, thin-film metal line resistor pattern was fabricated over the proposed shade structured multiple line bumps ($t = 500$ Å) with the width of 30 μm, as shown in Fig. 3(c). For the comparison, the identical line resistor patterns were also fabricated over the multiple line bumps without the shade structures (Fig. 3(b)) as well as on the flat surface without any bump (Fig. 3(a)) in the same process batch. Here, the line pattern of resistors has a length of 3 mm and a width of 30 μm, and is composed of molybdenum (Mo). Line resistors were patterned by the conventional photolithography process on SiO_2 layer (3000 Å) deposited by RF sputtering. Then we measured the resistance and the heat generated from each line resistor pattern over different topological ground, in order to see if any temperature difference by the proposed structure can be observed. Since molybdenum film, defined as the line resistors, has low emissivity (0.06) and high reflectance

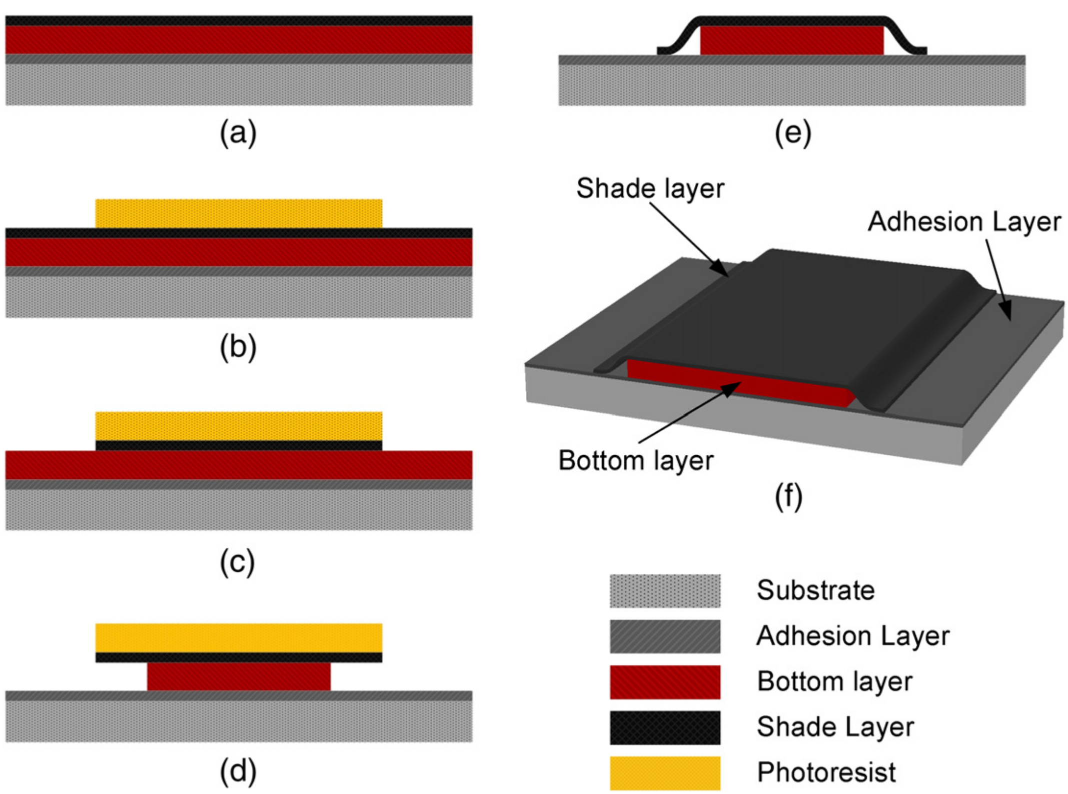

Fig. 2. The fabrication process of the shade structure. (a) The adhesion layer, bottom layer and shade layer are deposited on the wafer. (b) The photoresist is patterned by using a conventional photolithography fabrication. (c) The shade layer is patterned, and (d) bottom layer is over-etched in sequence by wet etching process. (e) The photoresist is stripped and a sample is spin-dried. (f) The schematic view of the completed shade structure.