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TECHNICAL PAPER

Fabrication of metallic micromirror using electroplating technology

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Abstract A nickel micromirror array was designed and successfully fabricated using a thick photoresist as a sacrificial layer and as a mold for nickel electroplating. It was composed of two address electrodes, two support posts and a nickel mirror plate. The mirror plate, which is supported by two nickel posts, is overhung about 10 μm from the silicon substrate. The nickel mirror plate is actuated by an electrostatic force generated by electrostatic potential difference applied between the mirror plate and the address electrode. Optimized fabrication processes have been developed to reduce residual stress in mirror plate and prevent contact between the mirror plate and the substrate, which ensure a reasonable flat and smooth micromirror for operation at low actuation voltage.

1 Introduction

Micromirror elements have widespread applications in optical systems such as flat panel displays, optical interconnects, adaptive optical arrays, scanners, optical beam steering, etc. (Van Kessel et al. 1998; Conant et al. 2000; Sun et al. 2005; Nee et al. 2000; Tsuboi et al. 2004; Ford et al. 1999; Singh et al. 2006). Bulk and surface micromachining are the most common technologies used for the manufacturing of actuated micromirrors. With bulk micromachining technology, micromirrors with good flatness can be obtained (Ford et al. 1999). However, geometries are limited by the process. Electrical interconnection is a major challenge due to the lack of conformal layers in silicon on insulator (SOI)-based MEMS, particularly for more sophisticated devices.

Alternatively, surface-micromachining has become an increasingly popular technology in recent years, with potential advantages over bulk micromachining involving adaptable device size, design flexibility and CMOS compatibility. Despite these advantages, surface micromachining also presents technological problems. Stress in the deposited thin films is the most important problem often causing bending of the micromirror platforms.

The object of this paper is to establish the fabrication process of a micromirror array using thick photoresist as a sacrificial layer; the micromirror utilizes electroplated nickel, a mechanically durable material with controllable residual stress, as the main structural material. It is an optimized fabrication process, in particular, which improves both the residual stress control and sacrificial layer etching process.

2 Micromirror structure

The structure of the micromirror is shown in Fig. 1. It consists of a nickel electroplated membrane and torsion beams connected to the address lines on a silicon substrate via two nickel electroplated anchors. Metal addressing lines and bottom electrodes are formed on the silicon substrate below the mirror plate.

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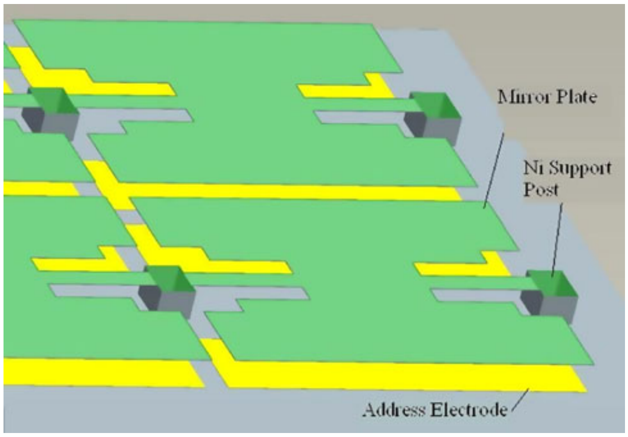

Fig. 1 The schematic view of the overhanging micromirror

3 Fabrications

A brief fabrication process is shown in Fig. 2. Fabrication of micromirror arrays started with 3 inch silicon substrates. Evaporated Cr/Cu (thickness of 300/700 nm) row addressing lines were patterned using the lift-off process (Fig. 2a). A PI layer was spin-coated to planarize the patterned metallic lines. A photoresist layer was spin-coated to protect the PI layer during the very last step of dry etching. Evaporated Cu (700 nm) column addressing lines (also serving as an electroplating seed layer for posts) were patterned using the lift-off process. AZ P4620 photoresist was spin coated on the seed layer and patterned by contact photolithography to obtain a micromold for electroplating the mirror support posts (Fig. 2b). After electroplating, the photoresist is baked at 100°C for 90 min and used as a sacrificial layer to create the air gap. The second seed layer Cu will be sputter deposited. A photoresist mold will be patterned and the top mirror plate and torsion beams will be deposited using nickel electroplating solution (Fig. 2c). The wafer is then diced and the bottom sacrificial layer is removed, as shown in Fig. 2d.

4 Results and discussions

4.1 Control of residual stress in mirror plate

Residual stresses are always present in thin films, which come from the fabrication process. The film stress could cause deformation of the mirror plate, reduce the fatigue life of micromirrors, and enhance corrosion and corrosion cracking, and this will highly affect the micromirror performance and lifetime. Therefore, the residual stress of the mirror plate has to be controlled in order to ensure the plate's integrity and reliability, which is especially important for micromirror. The Cu-Ni double layer structure of the mirror plate is selected to minimize the effect of process stress. Using finite element simulation as a guide, an experiment on the double layer structure was carried out to examine the bending of the mirror plate with different thicknesses of the Cu layers and Ni layers. A number of micromirrors (650 × 500 in size) were fabricated with Cu-Ni double layer structure. After released, the bending results were observed in a microscope. The results showed that the mirror plate with 800 nm Ni on top and 700 nm Cu on bottom had a tension stress [Fig. 3 (left)].

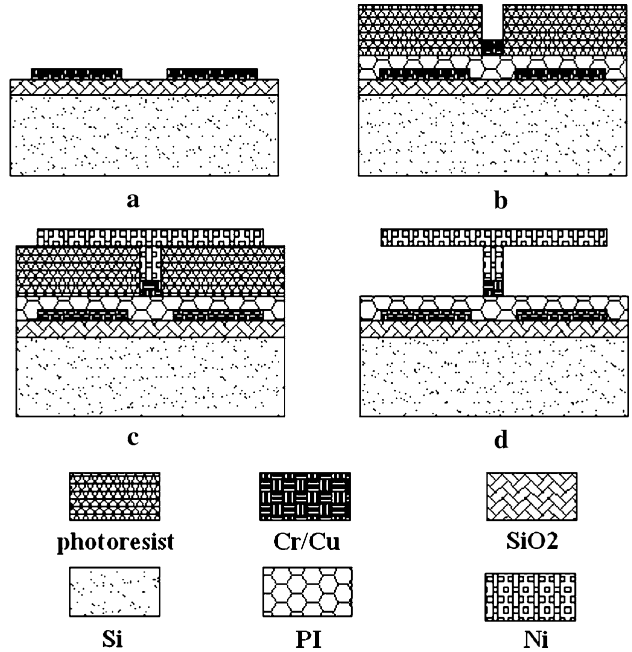

Fig. 2 Simplified process flow for micromirror

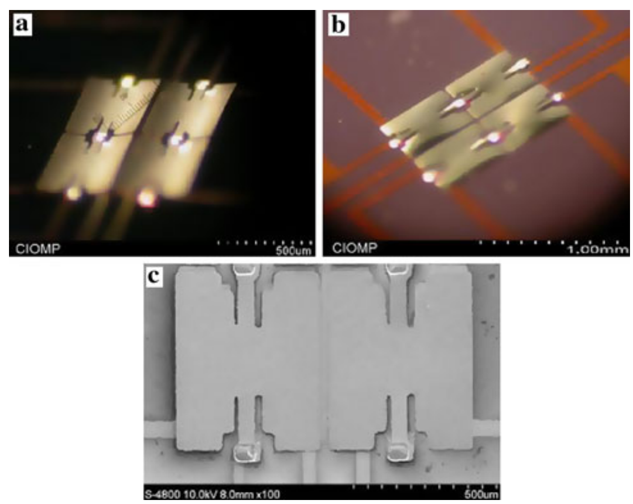

Fig. 3 The images of the micromirror residual stress test samples: **a** the thickness of 800 nm Ni on *top* and the thickness of 700 nm on *bottom*, **b** *top* Ni 1500 nm and the *bottom* Cu 700 nm and **c** *top* Ni 1300 nm and the *bottom* Cu 700 nm

The sample with a thicker top Ni layer (1500 nm) and same thickness bottom Cu layer (700 nm) displayed a compressive stress [Fig. 3 (right)]. A further reduction of the residual stress can be obtained by fine tuning the thickness of the Ni layers. As shown in Fig. 3c, we got a perfect flat mirror plate with top Ni 1300 nm and the bottom Cu 700 nm.

4.2 Sacrificial release and antistiction method

Sacrificial layer etching is often performed in liquid solutions because of the high speed of etching, simplicity of setup, and generally good selectivity. It is necessary to dry the wafer afterwards by natural or forced evaporation. However, many suspended, compliant micromechanical structures cannot survive the drying process without special designs and procedures. Often, contacts with the substrate are made. This failure mode of microstructures is referred to as stiction. Many practical methods have been developed to address the stiction issue (Srinivasan et al. 1998; Abe et al. 1995; Yee et al. 1995; Lee et al. 1998; Kim et al. 2001). In this work, we adopted a novel release method that combines dry and wet etching processes.

As schematically shown in Fig. 4, the sacrificial layer consist photoresist (AZ P4620) and photoresist post (BP218-60). Significant problems were observed when a normal hard baking temperature for the photoresist post was used in conjunction with the AZ P4620, because both the AZ P4620 resist and its developer readily attack photoresist post baked at 120°C. In order to avoid being attacked by solvents present during AZ P4620 application and wet etch release process, the cycle temperature and time for hard baking of the photoresist post are modified. The hard baking process shown in Fig. 5 is divided into three steps. First, the resist is put into an oven at 120°C. The oven temperature is ramped linearly to 215°C. For 5 µm BP218-60 photoresist post, the resist is baked at 215°C for 5 min and then cooled down to 100°C. The cool-down time is 25 min. The 5 µm BP218-60 photoresist post is completely hardened and is not affected by the AZ P4620 solution and acetone. When released, the AZ P4620 photoresist is removed by acetone, then, the wafer is dried by forced evaporation. As shown in Fig. 6a, the 5 µm BP218-60 photoresist post can prevent stiction between the mirror plate and the substrate. Finally, the the 5 µm BP218-60 photoresist posts are removed by O_2 plasma using ICP (Fig. 6b).

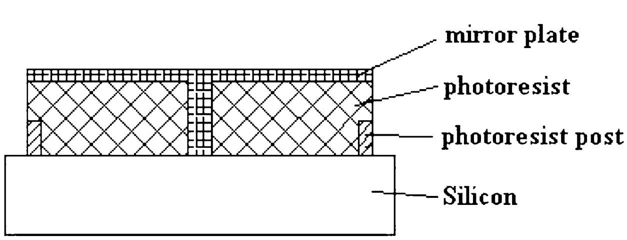

Fig. 4 Schematic of micromirror cross-section profile

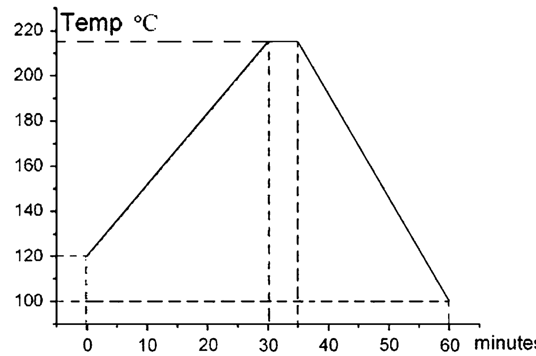

Fig. 5 Hard baking cycle for 5 µm BP218-60 photoresist post

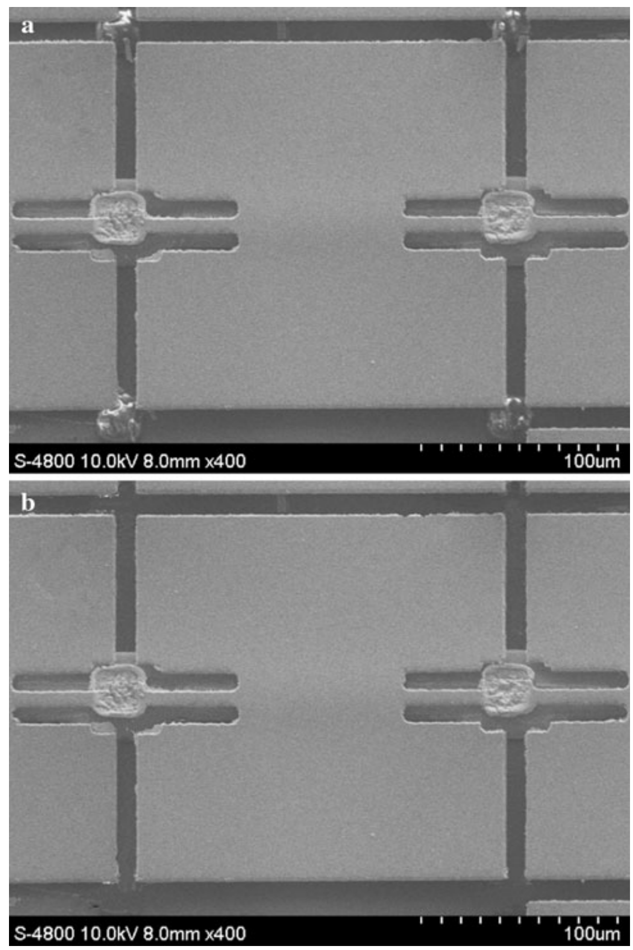

Fig. 6 **a** The micromirrors are released by wet etching. **b** After released by dry etching

Based on the experiments in residual stress reduction and sacrificial layer release process, first prototypes of micromirrors based on electroplating technology were

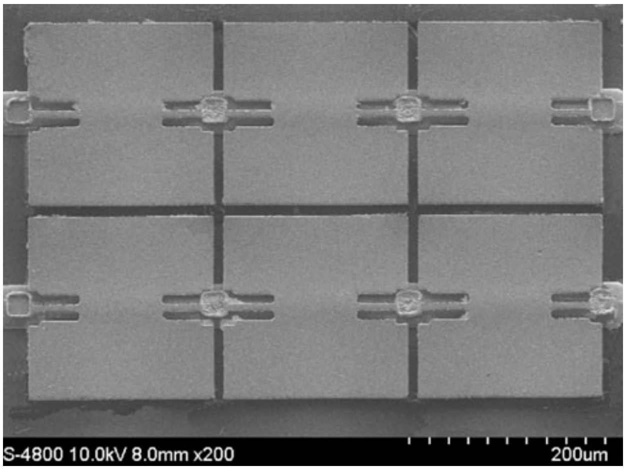

Fig. 7 SEM micrographs of a 2 × 3 array of nickel micromirrors

fabricated. A released mirror with plate dimension of 200 × 200 μm^2 is shown in Fig. 7. The gap between address electrode and mirror plate is about 10 μm.

5 Conclusions

One-axis metallic electrostatic micromirror array is designed and fabricated. The micromirror utilizes primarily electroplated nickel, a mechanically durable material with controllable residual stress, as the main structural material. The Cu-Ni double layer structure of the mirror plate is selected to minimize the effect of process stress. First prototypes of flat micromirrors with top Ni 1300 nm and the bottom Cu 700 nm were fabricated. A novel release method that combines dry and wet etching processes was adopted. The stiction can be reduced by using photoresist post. New hard cycles for BP218-60 resist have been determined to successfully withstand the wet etch release steps. The new hard baking cycle for BP218-60 is as follows: first, put the resist into an oven at 120°C, second, the oven temperature is ramped linearly to 215°C, third, bake at 215°C for 5 min and then cooled down to 100°C.

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