Fabrication of Low-Voltage Optical MEMS Switches by Using Seamless Integration Technology

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Optical MEMS switches have been attracting a great deal of interest as key devices for future photonic networks.[1][2] We have developed a reliable and practical method of integrating optical MEMS switches. The process features flexibility in the fabrication of an electrode structure designed to reduce drive voltage using add-on-type thick-plated gold multilevel interconnections for mirror-drive electrodes; anti-sticking technology afforded by screen printing to improve reliability; polyimide coating to protect the fragile and easily-movable micromachined mirror; and flip-chip bonding of the mirror and electrode chips by a screen-print technology. The maximum rotational angle of 1 ^{o} at 30 V was achieved using our developed technologies.

For microfabrication, we are developing Seamless integration technology (SeaiT) to combine MEMS components with LSIs on Si, taking into account all processes up to and including post-processing such as packaging.[3] Reducing device volume and achieving high functionality at the same time require the integration of optical MEMS switches with LSIs for control and sensing. The requirements for one-chip integration are as follows: (i) a drive voltage under 50 V achieved without large-area high-voltage devices, (ii) fabrication using a CMOS-compatible process, and (iii) a flexible electrode structure that can be fabricated practically. SeaiT's flexibility in design layout and low-thermal budget in fabrication[3] make it possible to build multilevel mirror-drive electrodes, which have the potential to be integrated with LSIs that have been made beforehand on a Si wafer. The fabrication method using SeaiT is thus advantageous over other optical MEMS switch fabrication methods using KOH-Si etching for making terrace electrodes[4] and poly-Si deposition at high temperatures for making mirrors.[1] SeaiT is also necessary to achieve reliable and high-yield integration of fragile Si-micromachined mirrors with the multilevel mirror-drive electrodes.

The aim of this work is to show the effectiveness of SeaiT for the formation of optical MEMS switches.

We made the electrode chip and mirror chip separately and then flip-chip bonded them together with silver paste as shown in Fig. 1. We designed the electrode structure to be suitable for low-voltage operation and made add-on-type multilevel interconnections with gold electroplating for the electrodes to drive the mirror. All the processes involved in forming the multilevel electrodes were performed under 310 ^{o}C, which provided >40-μm-high electrodes with 100% yield. This height ensures enough space for the rotation of the mirror placed over the electrodes. The movable mirrors, on the other hand, were sealed in polyimide during processing, which is the key to obtaining high yield. After packaging, the polyimide-sacrificial layer was ashed off, which completed fabrication.

As shown in the schematic structure of Fig. 1, a mirror is rotated by the electro-static force generated between mirror-drive electrodes beneath it and the mirror until the electro-static force is balanced with the elastic force of the Si-spring of the mirror. Figures 2 shows the control electrodes entirely coated by the polyimide film to prevent them sticking to the mirrors. Figure 3 shows images of the fabricated electrodes and an optical MEMS mirror switch fabricated using our developed technology. The angle-voltage characteristics in Fig. 4 demonstrate that the multilevel electrodes work well.

The results prove that our method of optical MEMS switch fabrication is practical and reliable, paving the way for integration with LSIs.

References

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[3] H. Ishii et al., Proc. Micromachining and Microfabrication Process Technology VII SPIE, 4557, 210 (2001).
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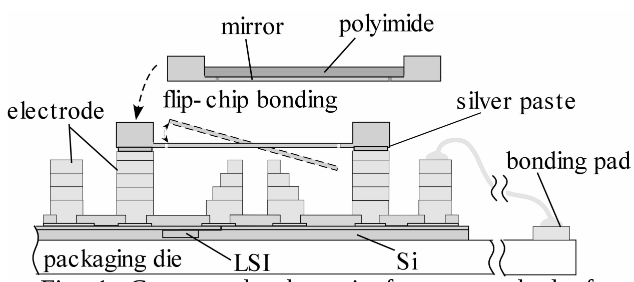

Fig. 1. Conceptual schematic for our method of fabricating optical MEMS switches.

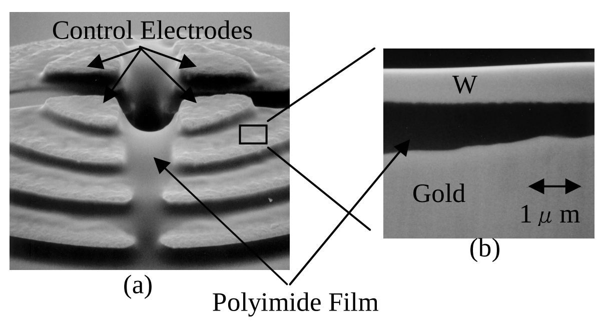

Fig. 2. SEM image of the film deposited on only control electrodes by screen printing technology and (b) a magnified image of the FIB cross section of the top electrode.

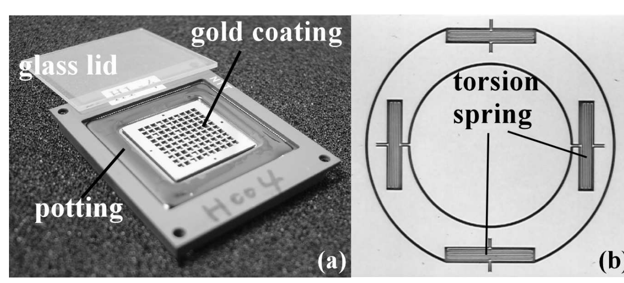

Fig. 3. (a) Completed optical MEMS switch, (b) Optical microscope image of mirror.

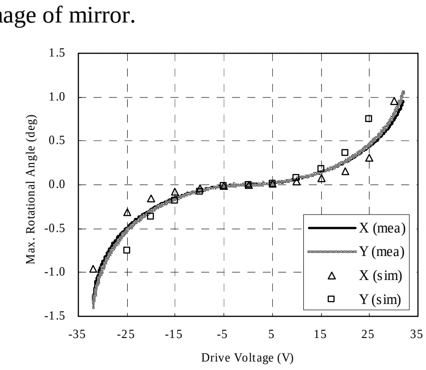

Fig. 4. Tilting angle of mirror vs. supply voltage.