PRACTICAL WAFER-COMPATIBLE FABRICATION OF NANOCRYSTALLINE SILICON THERMALLY INDUCED ULTRASOUND EMITTERS

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Due to complete carrier depletion by a strong quantum confinement, both the thermal conductivity and the heat capacity per unit volume of a nanocrystalline silicon (nc-Si) layer prepared by electrochemical anodization are extremely lowered in comparison to those of single crystal silicon.[1] Only by a single step process, a high contrast in the thermal property is produced at the nc-Si/c-Si interface. Utilizing this feature, we have developed novel thermally induced ultrasound emitter devices shown in **Fig. 1**.[2,3] To generate the ultrasound wave, an alternating current is supplied to a thin film electrode on the nc-Si layer followed by Joule's heating. Because of the almost complete thermal isolation in the nc-Si layer, efficient heat exchange occurs in the region in proximity to the front surface. The induced expansion and compression of air directly generates a sound pressure.

This new device with no mechanical vibrating components exhibits a flat frequency response over a wide range in contract to conventional airborne ultrasound devices such as piezoceramic transducers. Possible productivity of integrated arrayed structures by standard silicon planar processing is another important merit. To confirm the availability for practical processing, the present paper demonstrates that a wafer-compatible technology is useful for fabrication of this device.

The fabrication process employed here is as follows. The starting material was a p^--type silicon wafer with a diameter of 100 mm. First a thin SiC film was deposited by rf sputtering, and then partially removed by dry etching to form a mask. The sputtering conditions were optimized such that the patterned SiC film acts as an efficient acid-proof mask in the same manner to PECVD deposited a-SiC:H films.[4] The patterned SiC film also plays a role as an electrical isolator between the electrical pads.

The nc-Si layer was prepared by electrochemical anodization in a solution of 50 wt% HF:ethanol = 1:1 at a current density of 20 mA/cm^2 for 45 min. Next, thin film electrodes and electrical pads were formed as shown in **Fig. 2**. Finally, more than 300 square device chips (3×3 mm) were produced with a sufficiently high yield after dicing into chips. **Figure 3** shows photograph of a mounted device. The observed acoustic pressure emitted from the device is shown in **Fig. 4** as a function of frequency. We can see that as previously observed in the discrete device, the fabricated device exhibits a flat frequency response in a wide range.

In summary, we demonstrated that a wafer-compatible process is available for fabrication of thermally induced nanocrystalline silicon ultrasonic emitters, and that a sputtered thin SiC film is very effective as both a masking and an isolating layer. This technique makes it possible to fabricate micro-arrayed electrodes and to develop integrated silicon-based acoustic devices.

1. A. Drost *et al.*, Sens. Mater. **7**, 111 (1995).
2. H. Shinoda *et al.*, Nature **400**, 853 (1999).
3. N. Koshida *et al.*, Mater. Res. Soc. Symp. Proc. **536**, 105 (1999).
4. G. Muller *et al.*, Sensors & Actuators A **43**, 259 (1994).

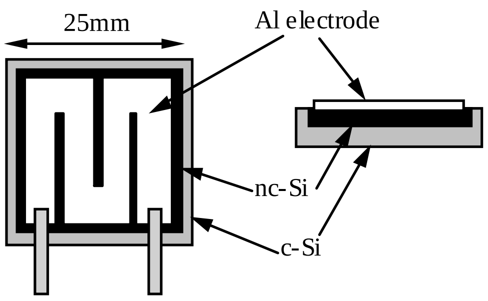

Fig. 1. Schematic illustration of a previously developed single-chip thermally induced ultrasound emitter (Left: top view, Right: cross sectional view).

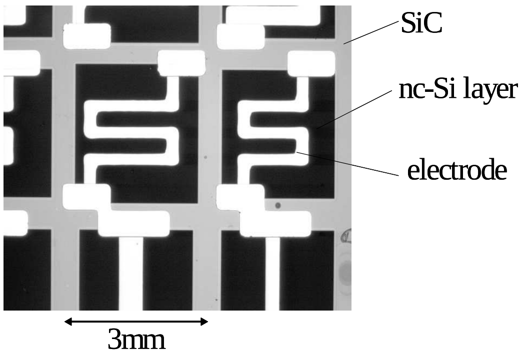

Fig. 2. Top view photograph of the wafer on which various types of nc-Si device are fabricated by practical processing.

Fig. 3. Photograph of the fabricated nc-Si ultrasound device. The chip (3×3 mm) is mounted on TO-5 housing.

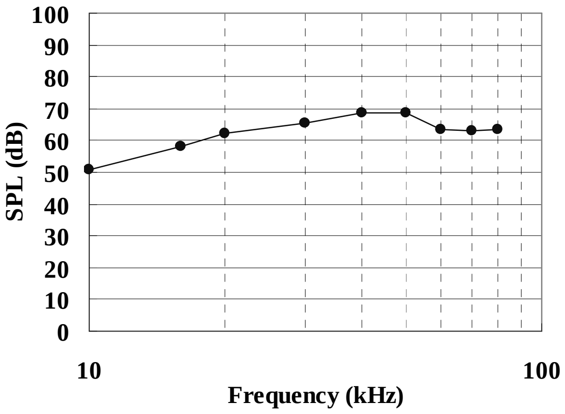

Fig. 4. Frequency response of the sound pressure level emitted from the device. A distance between the device and the microphone was 10 mm, and a supplied ac electrical input power was 1 W.