A HIGH-DENSITY TACTILE IMAGER FOR READING EMBOSSED CHARACTERS

Richard J. DeSouza and Kensall D. Wise

Center for Integrated Sensors and Circuits
Department of Electrical Engineering and Computer Science
The University of Michigan, Ann Arbor, MI 48109-2122

ABSTRACT

This paper describes a high-density high-compliance tactile imager suitable for reading embossed characters on credit cards. The sensor has 16 flexible silicon shanks arranged in a single row. Each shank is 6mm long, 100µm wide and 10µm thick. Piezoresistive strain gauges incorporated on the shanks give a high-sensitivity analog readout as the tips of the shanks deflect over characters on the scanned card surface. Fabrication is accomplished using a five-mask single-sided bulk-micromachined dissolved-wafer process. The devices have a sensitivity of 10mV/mm at 5V and a minimum resolution of 1µm. The fabrication process is compatible with the realization of shanks on 50µm centers and allows a high degree of design flexibility in setting device performance for a variety of surface profilometry applications.

INTRODUCTION

Magnetic strips are currently employed worldwide to carry information on credit cards for use in financial transactions. However, it is not uncommon for the strips to fail, and a backup system is badly needed. It is widely believed that a tactile imaging system can provide a low cost alternative to allow the card number and perhaps other information to be read automatically when the magnetic strip is no longer functional. As more and more financial dealings are implemented using credit cards and other card-access systems, the need for such imagers is becoming increasingly evident. However, the devices must be low-cost and capable of working reliably over hundreds of thousands to millions of scan operations in environmental conditions that can include large temperature variations and high humidity.

Over the past decade, there have been a variety of semiconductor-based approaches to the realization of high-resolution tactile imagers [1-4]. Among the more promising recent devices are those based on x-y organized capacitive arrays, either bulk- or surface-micromachined [5,6]. For the work reported here, a bulk-micromachined capacitive-cell approach [5] was first explored. This device used a 500µm pixel spacing with a split-boss arrangement capable of producing an effective spatial resolution of 250µm. The doubly-supported capacitive bridge cell exhibited low noise, high sensitivity, and high resolution. However, profilometer scans of typical cards show height irregularities in the embossed characters of 50µm or more. This is a serious problem with most previously reported solid-state imaging arrays since their total vertical compliance is typically limited to a few microns. Vertical compliance can be increased using a deformable pad overlay, but with degraded spatial resolution. As a result, we altered our approach to a high-density multishank linear piezoresistive array based on a modification of the neural probes we have been developing for a number of years [7,8]. This "microbrush" array is scanned across the card surface to read the characters. This approach overcomes the vertical compliance problems of planar arrays and has been designed to read the entire credit-card account number in a single scan.

DESIGN CONSIDERATIONS

The design of the new device was governed by the specifications on the dimensions and position of the account number on credit cards set by the American National Services Institute for financial services [9]. The number field on the credit card is about 5mm x 68mm in size with the height of the embossed characters being typically 500µm above the front surface of the card. The width of the lines that form the numbers is 0.51mm, and this decides the maximum allowable pitch between consecutive shanks to achieve sufficient resolution. Although theoretically either side of the card could be used for the scans, labels sometimes obscure portions of the back side, making the front side a more appropriate target surface.

A top view and cross-section of the tactile imager structure is shown in Fig. 1. For the present 16-shank prototype arrays, each shank is 6mm long, 100µm wide, and 10µm thick. The shanks have a center-to-center spacing of 400µm, resulting in a scan line 6.4mm wide. This gives sufficient resolution as well as some tolerance for any misalignment during a scan. In the future, a 64-shank imager will be implemented to increase the present resolution by another factor of four. Two polysilicon resistors are provided per shank, arranged in a half-bridge configuration so that ambient temperature sensitivity due to the TCR of the resistors is suppressed. One resistor is located at the base of the shank, where maximum stress is developed. It acts as piezoresistive strain gauge and gives a high-sensitivity analog readout. The other resistor is located on the rear of the substrate and is used as the reference. The shank tips deflect as they go over the embossed characters, and the corresponding change in strain results in an electrical output signal.

The strength of each shank can be analyzed by considering it to be a cantilever beam [10]. The fracture stress is a weak function of the shank thickness and is over an order of magnitude higher than the maximum levels expected in use. This is important since the brush must be able to reverse direction against the scanned characters without damage. Shanks can be elastically bent through angles of more than 90° (corresponding to radii of <400µm) without damage.

FABRICATION

Fabrication begins with standard p-type <100> silicon wafers that are first oxidized and patterned to define the intended tactile sensor areas. The patterned areas are subjected to a deep boron diffusion that forms the base of the sensor, acting as an etch stop for the final EDP etch. An optional shallow boron diffusion can also be used to define a thinner area of the probe shank to concentrate bending under the strain gauge and optimize its sensitivity. Next, LPCVD dielectric layers consisting of an oxide-nitride-oxide combination are deposited. Then polysilicon is deposited and patterned to form the strain gauges. Upper dielectric layers which are similar to the lower dielectrics are deposited and contact openings are patterned and etched.

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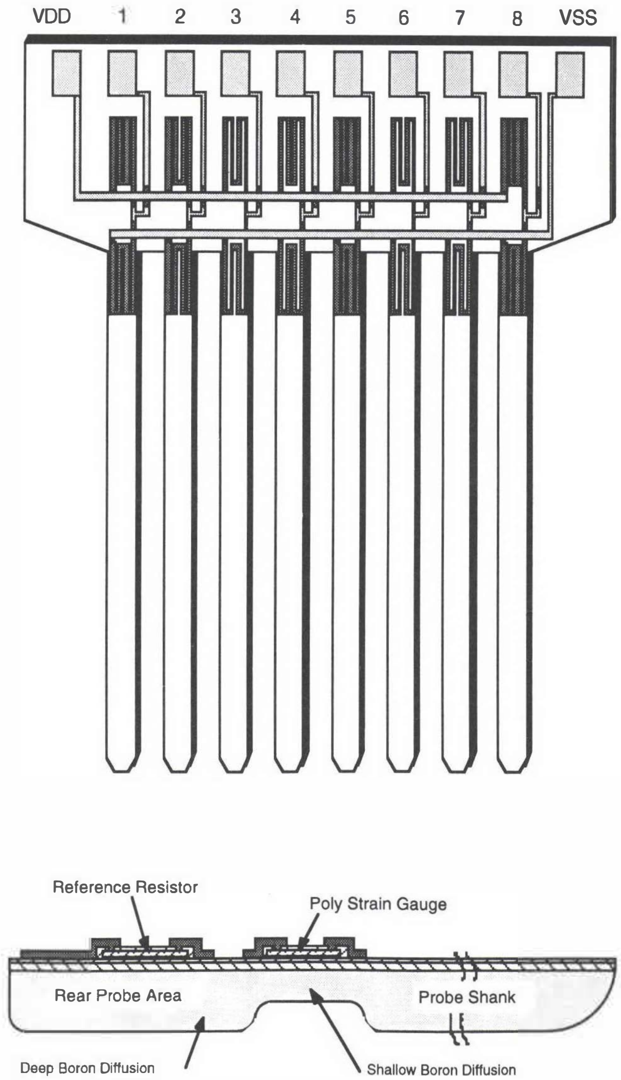


Fig. 1: Top view and cross-section of a bulk-micromachined tactile imager. Independent shanks, each containing an integrated strain gauge, brush over the substrate, creating an electrical image of the surface topography.

A 500Å-Cr/3000Å-Au metallization layer is sputtered onto the wafers, and a lift-off process is used to define the metal interconnects and bonding sites. The dielectrics are now etched from the field areas. Finally, the wafers are thinned from the back-side to a thickness of about 150μm in an isotropic etch (10% HF, 90% nitric acid) and are then subjected to an unmasked etch in ethylene diamine pyrocatechol (EDP), which dissolves the lightly-doped silicon substrate but does not significantly attack silicon doped with boron in concentrations higher than about 7 x 10^{19} cm^{-3} or any of the other exposed materials. The overall fabrication process is single-sided on wafers of standard thickness and requires only five masks. The process is also compatible with a standard CMOS process [8], making it straightforward to incorporate on-chip circuitry in the future. Such circuitry will be important in providing the first-level amplification and multiplexing necessary to ensure high signal-to-noise ratios and environmental immunity on arrays involving higher numbers of channels. It is also important to note that the neural probes, which have a structure similar to these imagers, are known to be compatible with long-term use in saline. Hence, the imager structure should offer ample environmental immunity for credit card applications. Figure 2 shows two views of a completed 16-shank device, while Fig. 3 shows a SEM view of the tip of a shank. Figure 4 shows the strain-gauge area at the base of a shank.

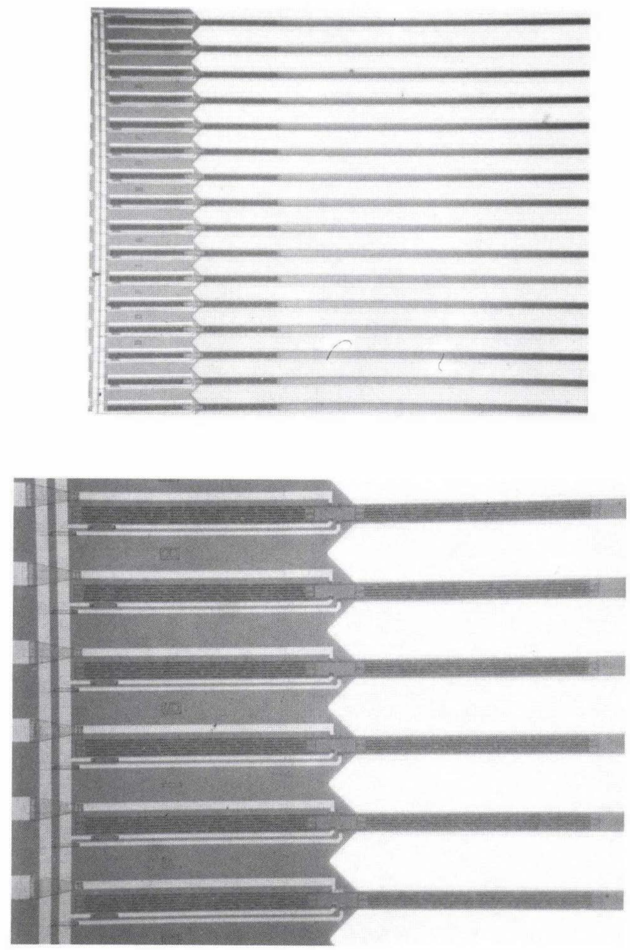


Fig. 2: Top views of a 16-shank tactile line imager showing the overall device (above) and a detail of the strain gauges at the rear of the substrate. The shanks are on 400μm centers.

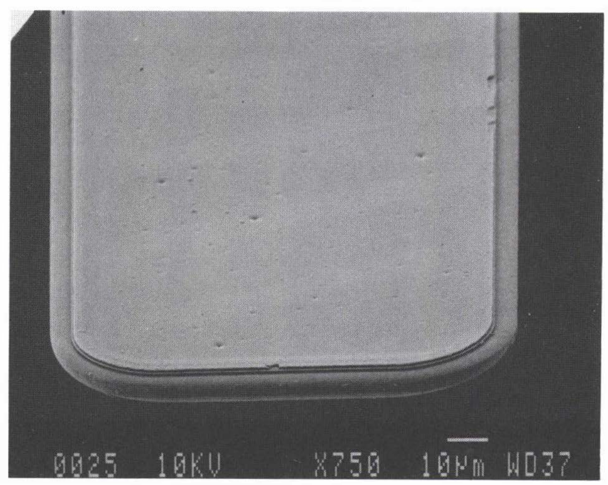


Fig. 3: SEM view of the tip of a microbrush shank.

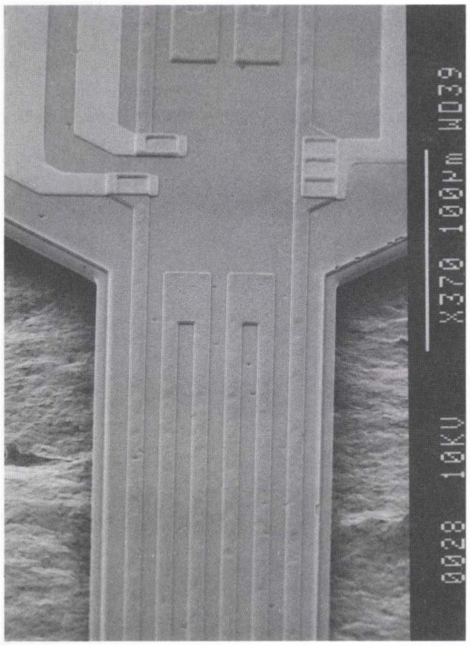


Fig. 4: SEM view of the strain gauge at the rear of a microbrush shank. The shank width is 100µm.

DEVICE PERFORMANCE

Tests conducted on typical devices have shown that the strain gauges have a sensitivity of 10mV/mm when operating from a 5V supply. This corresponds to a gauge factor of 19 (Fig. 5), which matches previously published data [10] as well as theoretical calculations. Because the height of the embossed characters is about 500µm, an output signal of at least 5mV is obtained, resulting in an excellent signal-to-noise ratio. Assuming an electrical noise level of 10µV, the minimum resolution is 1µm.

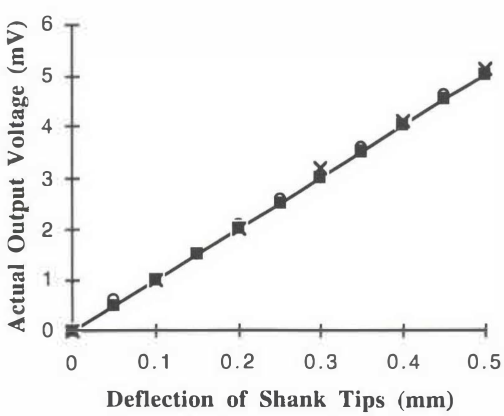
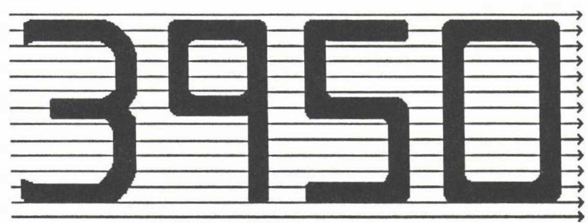
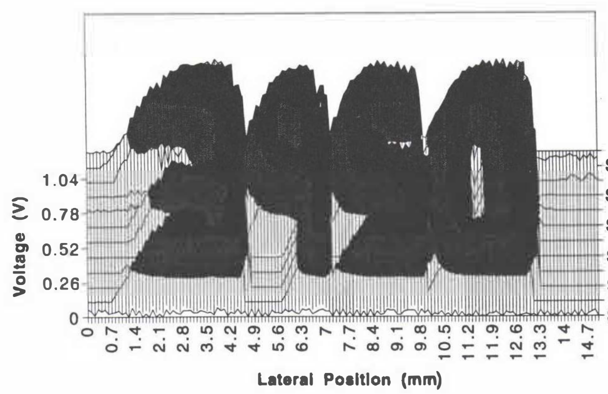


Fig. 5: Output characteristic of the tactile sensor with offset correction for several sets of data. The supply voltage is 5V.

Scans have been made on several different credit cards with the microbrush brought in contact perpendicular to the front surface of the cards. A z-micropositioner was used to accurately set an initial deflection on the tines so that they always touch the card surface even when not over a character. The output from each channel is amplified using a difference amplifier and fed to a computer through a data acquisition board. A reading taken with only the initial deflection determines the offset correction values. A sample scan is shown in Fig. 6 with the output being displayed as a 3-D surface plot using Microsoft Excel. No other image processing was performed. Figure 6(a) shows the credit-card numbers and the tracks along which the microbrush shanks contacted the card surface. Figure 6(b) shows the resulting analog outputs with the image of the numbers clearly recognizable. The scan speed was 15mm/sec and the scan interval was 6.67msec, giving a 100µm lateral resolution. The sampling frequency between successive channels was 100kHz, resulting in a skew of less than 2.4µm per scan interval. Using an optical encoder to keep track of lateral distance during a scan makes it possible to have scan speeds of 50mm/sec or more so that the entire account number can be read in less than two seconds.



(a)



(b)

Fig. 6: Sample scan of the embossed characters "3950" on a credit card (above) and the corresponding output plot represented as 3-D surface (below).

CONCLUSIONS

A high-density high-compliance tactile imager for reading embossed characters has been reported. The present 16-shank line imager has shanks that are 6mm long, 100µm wide and 10µm thick with a 400µm pitch. It is scanned across the front surface of the credit-card, permitting the entire account number to be read in a single scan. Polysilicon strain gauges give a readout sensitivity of 10mV/mm and a vertical resolution of about 1µm. Fabrication is accomplished using a well-developed five-mask single-sided dissolved-wafer process that is capable of producing imagers having a lateral resolution as small as 50µm. The devices are immune to most environmental conditions, and the process technology is CMOS compatible, making it possible to incorporate on-chip circuitry on such arrays in the future. This high-compliance tactile sensor can easily be optimized for use in a variety of surface profilometry applications requiring vertical resolution in the range from one micron to several thousand microns. The microbrush is being built into a feedback system to automatically control device positioning and perform dynamic compensation for offsets during a scan.

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