行政院國家科學委員會專題研究計畫　成果報告

覆晶式封裝微力感測器之設計、製作及測試

計畫類別：個別型計畫
計畫編號：NSC93-2215-E-009-055-
執行期間：93 年 08 月 01 日至 94 年 07 月 31 日
執行單位：國立交通大學電子工程學系及電子研究所

計畫主持人：黃宇中

計畫參與人員：丁沛熙

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一、中文摘要

微電子產業中晶片與玻璃之夾持，對於力大小的量測將有助於對接觸物體的認知或施力大小的控制。本計劃以微機電製程實現可量測力大小之感測器。所提出之新式微力感測器將以多晶矽壓阻作為感測元件，並以位於圓形之薄膜中心的凸出物作為力之導引結構。於微感測器製作前，所提出之新型力感測器結構於受力時之縱向/橫向應力及應變之分佈將被分析。分析所得之微力感測器靈敏度及感測範圍將作為設計微力感測器光罩之依據。微力感測器的微製程將製作出的微感測器具4×4 mm及於0.5v的輸入電壓條件下具4.95μV/g.w.的靈敏度。量測的結果和所建立的模形相當吻合。

關鍵詞：多晶矽壓阻、微機電系統、微力感測器

Abstract

In the microelectronic industry micro force sensors that measure the magnitude of the normal contact force are proposed and fabricated by micromachining technologies in this project. Piezoresistive poly-Si on an insulating layer will be used as sensing elements and a circular membrane with a center boss serves as the force conducting structure. The analytic solutions of the distribution of the deflection and the longitudinal/transverse stress of the sensor upon a contact force is derived to obtain the sensitivity and the working range of the sensor. Then, the sensor according to the design was fabricated. The fabricated micro tactile sensor had a dimension of 4×4 mm and used poly-Si on an oxide layer as piezoresistors. After measuring, it has a sensitivity of about 4.95 μV/g.w. at a supplying voltage of 0.5 V and room temperature. The measurement result agrees with the sensor model very well.

二、緣由與目的

When a robotic hand tries to grasp an object, sensors are needed to help the hand to know the magnitude, the position and the direction of the force or the torque applied on the object. Therefore, the robotic hand can take the object stably and safely. The so-called fingertip sensors are used to accomplish these tasks. Fingertip sensors have been categorized into intrinsic force/torque sensors and extrinsic tactile sensor [1][2]. Not like the intrinsic tactile sensor, which detects more than one degree of the force and torque at one device, the extrinsic one detects the contact force at the only single point and the normal direction. With collecting of many extrinsic tactile sensors in a 2-dimensional space, the tactile sensor array is formed and, thus, a force image of the contacted object can be obtained. In recent years, many tactile sensors were proposed based on different materials, structures and fabrication methods[3-9]. Besides their good performance, however, none of them are proven to dominate the market maybe due to the cost[10]. Because they either use a special material to sense the force or complex packages to

introduce the force to the sensor. To ease these problems, the most successful product based on MEMS (Micro Electro-Mechanical System) processes, the piezoresistive pressure sensor[11], was considered and had been used as a piezoresistive tactile sensor[12-15]. Regarding the same advantages of piezoresistive pressure sensors, piezoresistive tactile sensors provide a high sensitivity, good linearity, low hysteresis, easy sensing circuit and a way to batch processes. However, those proposed tactile sensors require still additional package to introduce the force to the sensor because there is no force-conducting structure on the membrane. Moreover, in these previous researches, the distribution of the stress in the membrane of the sensor has not been analysed in detail when a contact "force" instead of a "pressure" is applied on the sensor since the behavior of a force on a sensor is quite different from a pressure on a sensor. Therefore, in this paper, a piezoresistive tactile sensor with a circular membrane and a center boss is proposed and analysed in order to give a design concept. It is known that a piezoresistive pressure sensor with a circular membrane and center boss has higher sensitivity and better linearity than one without center boss[16]. Moreover, the center boss on the membrane can provide a structure for a force introduction which could reduce the complexity of the manufacture and the cost.

三、研究成果

After the successful fabrication of the center-boss tactile sensor in the last year's project (NSC-92-2218-E-009-011), this project focus on the package and the characterization of the fabricated sensor. Fig. 1 illustrates the usage of the fabricated tactile sensor. The center boss which is a little higher than the surrounding frame is used to conduct the applied force. This structure will limit the further movement of the contacting object. In addition, as the deflection of the membrane is larger than the distance between the sensor and the bottom plate, which may be a glass or a ceramic, the plate will also constrain the further movement of the sensor and, therefore, avoid the further deflection of the circular membrane. As a result, the sensor will not be destroyed if an over-range contact force is occurred. This distance can be determined once the deflection function of the membrane is obtained. The static performance of the fabricated sensors is characterized by a mechanical system illustrated in Fig. 2. The sensor is attached on a PCB (Printing Circuit Board) by silver adhesives and the signals on the sensor are connected by the conducting lines on the PCB and to the next side of PCB by aluminium pins. A known weight is used as the applied force and is conducted to the sensor by a needle that is supported by a Teflon block. The weights are first added and, than, removed to obtain the forward and backward measurement results. A programmable voltage source (Keithley 230) and a multi meter (Keithley 196) are connected to the sensor properly to read the change of the voltage at room temperature. The result is shown in Fig. 3. As we can see, the offset of the sensor is about –8.54 mV. The sensitivity of the sensor is about 4.95 μV/g.w. when 0.5 V is applied to the Wheatstone bridge. The non-linearity of the sensor is 1.5% and the hysteresis is 4.3%.

A curve according to the previous developed analytic solution is also drawn in the same figure by using the geometry of the fabricated sensor. A gauge factor of –6.3 [18] is taken because of the highly

doped n-type poly-Si piezoresistors. With an adding of the offset voltage, the analytic solution agrees the measurement very well.

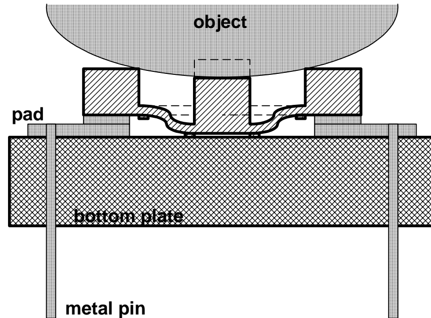

Figure 1. The usage of the fabricated tactile sensor.

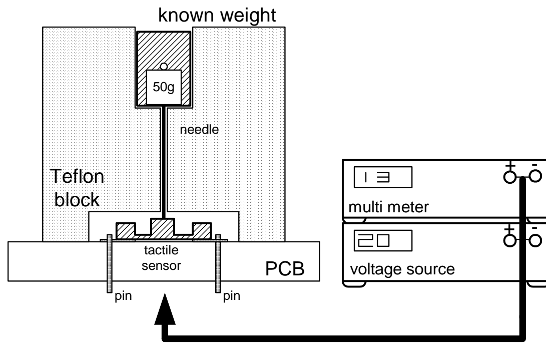

Figure 2. The setup to characterize the fabricated tactile sensor.

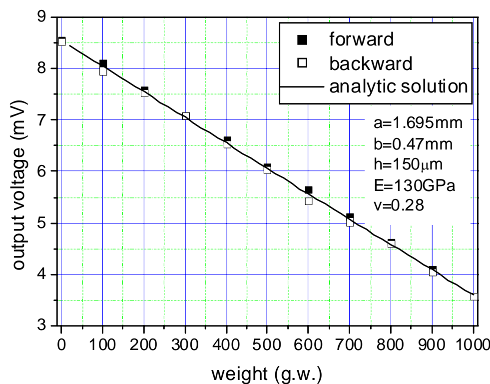

Figure 3. The measurement result of the tactile sensor.

四、結論與展望

A tactile sensor based on a circular membrane with a center boss have been analysed, fabricated, packaged and characterized in this two-year project. The distribution of the deflection and the longitudinal and transverse stress of the sensor due to a contact force are obtained and verified by FEM and experiment. Because the stresses at the inner and outer edge of the annular membrane are not the same, a non-balanced Wheatstone bridge is used in the design of the tactile sensor to keep the high sensitivity of the sensor. It has been proven, the non-linearity caused by such a non-balanced Wheatstone bridge can be neglected. Since the fabrication process of the proposed tactile sensor is the same as the conventional pressure sensor with a center boss, the cost of the sensor could be reduced because no other special materials or processes are used. Further more, a packaging and the design guide of an over-range protection are described to make the sensor practical. Tactile sensors, which have a sensing range to 1 kg.w. and a sensitivity of 4.95 μV/g.w. at 0.5 V, are fabricated to demonstrate the feasibility of the proposed tactile sensor.

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