Monolithic Silicon Fabrication Technology for Flexible Circuit and Sensor Arrays

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Abstract

Arrays of circuit elements are fabricated on the surface of a silicon wafer and are interconnected by gold metallization. A layer of polyimide is then formed on the wafer surface by spinning on a layer of polyamic acid and curing it at high temperature. Masking and etching from the backside of the wafer leaves separate silicon islands supported on a flexible polymide substrate, interconnected by the flexible gold metalization. Size is smaller than tape-bonded hybrids. Applications include linear thermometer arrays and two-dimensional arrays of sensors for robotic and biomedical uses.

Introduction

This research has been driven by the need to measure temperature profiles in living tissues during hyperthermia treatment of cancer. To measure such profiles, some minimally invasive means of inserting arrays of thermometers into a tumor is necessary [1]. Such thermometer arrays should have low thermal conductivity for accurate temperature measurement, and should be physically pliable and small in size for minimum tissue trauma during patient movement. They should also be fairly inexpensive to fabricate for low cost in clinical use. We previously developed a hybrid assembly technique to fabricate linear arrays of six thermometers which were small and flexible [2], but these arrays proved to be too difficult to fabricate in volume, and were not durable enough for in-vivo use.

We have developed a new, totally monolithic method of fabricating linear arrays of twenty silicon diodes which act as thermometers. The technology results in separate silicon islands supported on a thin, flexible polyimide substrate. Gold wires encased in the polymide provide electrical interconnection of the islands. To date only passive silicon diodes have been fabricated on each island, but the technology can be used to fabricate transistors and active signal processing circuitry. The fabrication techniques are simple and preliminary yield data is good.

Fabrication Process

The method of fabrication runs as follows:

1. Use conventional integrated circuit techniques to fabricate circuit elements on one surface of a silicon wafer.
2. Interconnect the circuit elements with thin gold leads. We use 1 micrometer thick gold with an adhesion layer beneath the gold, and a diffusion barrier in the device contact holes.
3. Spin on an adhesion promoter to make polyimide stick to silicon dioxide. Spin on a layer of polyamic acid, and slowly raise the wafer temperature to 350 C to imidize the polyamic acid and form a polyimide layer. The diffusion barrier mentioned in the preceding step is necessary to prevent alloying of the gold with the silicon at the 350 C cure temperature.
4. Open holes in the polyimide layer over contact pads on the wafer frontside.
5. Mask and etch the wafer backside in a hydroflouric acid/nitric acid mixture, forming separate silicon islands. The metal lines are exposed at this point, and are supported by the polyimide substrate.
6. Add more polyamic acid on the wafer backside and cure to 350 C. This step encases the silicon islands and gold leads in a solid layer of polyimide.
7. Cut out individual arrays with a scalpel.
8. Test and package the arrays.

The structure of a flexible array is illustrated in Figure 1.

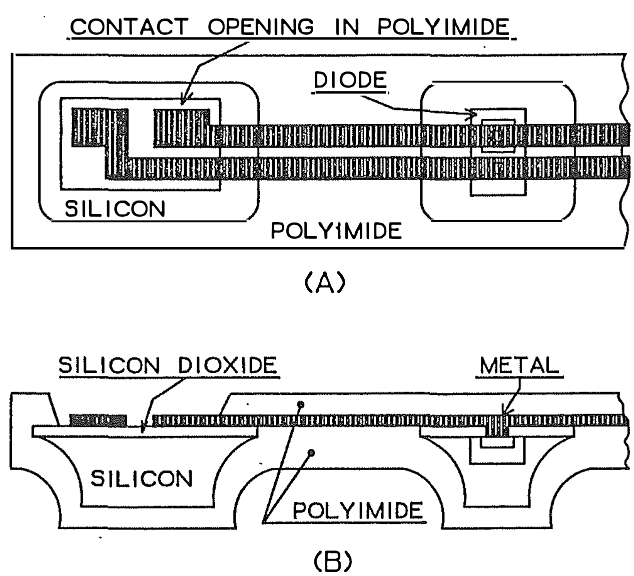

Figure 1: Flexible array. (a) Plan view, (b) Cross-section.

Application to Thermometer Arrays

Three versions of linear thermometer arrays are under development. 3.5-cm long arrays of twenty diodes have been fabricated on 5-cm diameter silicon wafers, tested, and packaged. These arrays are useful test vehicles but are too short for most clinical applications. On 7.5-cm diameter silicon, 10-cm and 20-cm long arrays are being fabricated as of this writing. The 10- and 20-cm arrays are long enough for use in most human tumors.

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The interconnection technique for the diodes in the 3.5-cm arrays has been explained previously [2], and allows the use of Nx(N-1) sensors on N wires (in this case, 20 diodes on 5 wires). Our present mask set allows fabrication of 22 of the 3.5-cm arrays on a 5-cm silicon wafer. For the 10-cm and 20-cm arrays we have modified the multiplexing technique for a 4-terminal measurement at each diode to reduce any errors due to resistive drops along lead wires. The modification results in doubling the number of lead wires, giving 10 leads for a 20-diode array.

To allow 10-cm and 20-cm arrays to be fabricated on a 7.5-cm diameter wafer, it is necessary to form the arrays on the wafer as a meandering shape. During the final assembly and packaging process, the meandering shape can be slit to the proper shape with a scalpel, folded out to form a long linear array, and glued at the folded joints to make it hold its shape. We are presently fabricating six of the 20-cm arrays plus four of the 10-cm arrays on each 7.5-cm diameter wafer.

All three types of thermometer arrays are small enough to be inserted into hollow needles or catheters, or glued onto a needle or other probe, for insertion into tissue. Packaging techniques are still under development.

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References

[1] IEEE Transactions on Biomedical Engineering, Special Issue on Hyperthermia and Cancer Therapy, Vol. BME-31, No. 1, January 1984. (See especially the paper by Parker, pp. 161-167.)

[2] Phillip W. Barth and James B. Angell, *"Thin Linear Thermometer Arrays for Use in Localized Cancer Hyperthermia"*, IEEE Transactions on Electron Devices, Vol. ED-29, No. 1, pp. 144-150, January 1982.