A MICRO-MACHINED PYROELECTRIC DETECTOR ARRAY

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ABSTRACT

Using a novel bulk silicon micro-machining technique, an infrared detector has been fabricated for use in medical monitoring products. The device employs a thin ($<5\mu\text{m}$) free-standing membrane of poly(vinylidene fluoride-trifluoroethylene) (P(VDF/TrFE)) co-polymer supported by a silicon frame. IR light incident upon a semi-transparent Cr lower electrode is absorbed by the membrane, producing a voltage between this electrode and a series of Cr/Au electrodes on the top. In this configuration, 74 electrodes provide spatial resolution that corresponds to spectral resolution when the device is mated to a linearly-graded IR filter.

INTRODUCTION

During certain medical procedures it is desirable to monitor the concentration of gases within various media. The ability to provide this information on a real-time basis with minimal signal conditioning is a key requirement, along with low cost and reliable operation. Absorption spectroscopy using a near-infrared source can meet these constraints, provided that a suitable detector is available. Photoconductive and photovoltaic semiconductor devices can be used, but these usually require external cooling from a Peltier junction in order to increase the signal-to-noise ratio. As an alternative, the incident radiation can be coupled into a ferroelectric material. The highly anisotropic crystalline structure of a ferroelectric will produce an electric field when the lattice is strained; when strain is induced by localized heating, the effect is known as pyroelectricity.

Recently, a number of researchers have investigated the use of poly(vinylidene fluoride-trifluoroethylene) (P(VDF/TrFE)) co-polymer thin-films as pyroelectric sensing agents [1-7]. This material system is particularly well-suited for integration into microfabrication processes, since it can be applied to a substrate by spin-on from a solvent-based precursor. CMOS devices fabricated in the substrate can be used for amplification and signal processing. However, thermal conduction from the sensing film to the substrate can limit sensitivity. To circumvent this problem, Kohler, et.al. [8] and Setiadi, et.al. [9] describe devices where the co-polymer film is supported by a silicon nitride membrane formed by anisotropic etching of the silicon substrate.

The device presented here employs a completely free-standing co-polymer film, supported by a silicon frame. As shown in Figure 1, 74 electrodes are fabricated along the top of the device, and a thin layer of Cr is used for the bottom electrode. The thickness of the co-polymer membrane is adjusted to provide optimal absorption at the wavelengths of interest. The resistivity of the bottom electrode is targeted to be $377\Omega/\text{sq.}$, matching the impedance of free-space.

Figure 1. Isometric view of sensing array.

FABRICATION

Figure 2 shows the fabrication sequence. A 75mm silicon wafer that has been back-lapped and polished to a thickness of $285\mu\text{m}$ is cleaned and thermally oxidized to $1\mu\text{m}$. A chromium film $1000\text{\AA}$ thick is sputter deposited onto the back of the wafer. The Cr and oxide layers are patterned and etched and used as a mask for a backside silicon etch in 25% TMAH at 80°C to form the frame for the device. The TMAH etch is carefully timed and monitored to obtain $50\mu\text{m}$ thick Si diaphragms. Each wafer contains 19 diaphragms measuring approximately $4\text{mm} \times 11\text{mm}$. The separation webs for the devices are also formed during this step, eliminating the need for a potentially damaging dicing operation. The diaphragms are quite robust and can be subjected to moderate vacuum ($2\text{-}3''$) during lithographic operations. (Spin coating is performed with a vacuum-less chuck).

A window is patterned in the oxide on the front of the device (using IR alignment), and a thin ($\sim 100\text{\AA}$) layer of Cr is deposited to form the bottom electrode. As noted above, the sheet resistivity of this layer is controlled to $377 \pm 50\Omega/\text{sq.}$ to match the impedance of free-space. Simulations of the absorbance vs. wavelength indicate that a variation of $200\text{-}500\Omega/\text{sq.}$ has little effect on the overall performance of the device. After patterning the Cr, a solution of 70%/30% P(VDF/TrFE) copolymer dissolved in butanone is applied to the substrate by spin-on at 4KRPM. The co-polymer is baked at 105°C for 1 min. on a hot plate. A $1000\text{\AA}$ thick layer of copper is sputter deposited to act as a mask for etching the co-polymer in an O_2 plasma, which also strips the photoresist. The copper is removed in a solution of ferric chloride after the co-polymer etch. A layer of $200\text{\AA}$ Cr/ $3000\text{\AA}$ Au/ $300\text{\AA}$ Ti-W is then deposited and patterned to form the top electrodes. The PR

from this mask is stripped by flood exposure and development, which does not affect the co-polymer film. The Ti-W is stripped in H_2O_2 to remove any remaining PR residue.

Figure 2. Fabrication sequence.

The front of the wafer is coated with Ti-W/Cu to protect the gold electrodes during the release etch. (We have observed that Au is attacked by XeF_2 , as reported by others [12]). After a 50:1 HF dip and a 95°C dehydration bake, the wafer is placed face-down on a Teflon holder in a home-built XeF_2 pulse etcher (Figure 3). This etching method was chosen for its extreme selectivity to oxide and other materials and its gentle characteristics [10,11]. This step also releases the die from the wafer. The die etch at slightly different rates, requiring an overetch that does not affect any of the devices. For a etch/pump cycle of 7s/5s it takes about 3 hours to completely remove the diaphragms. The chamber pressure during the etch interval is about 2.2T. None of the membranes are damaged by the etching process. A SEM photo of the released film (Figure 4) also shows rounding of the TMAH-etched corners from the XeF_2 etch.

Figure 3. Photograph of XeF_2 etching system.

After release, the individual die are transferred to a polypropylene holder to facilitate handling. The holder is arranged in a radial configuration to allow the die to be processed by placing the holder into a standard wafer carrier. The Cu and Ti-W protection layers are then removed in $FeCl_3$ and H_2O_2 , respectively. The co-polymer is then annealed at 140°C for 6 hrs., followed by a 12 hr. cooling ramp to room temperature. A photograph of a completed device is shown in Figure 5.

Figure 4. SEM of released membrane.

Figure 5. Photograph of completed die.

RESULTS

The individual devices are poled by applying 180V across the electrodes in three cycles of 10 seconds duration. After each cycle the polarity is reversed. Characteristics obtained from devices fabricated at CRL using a precursor process are shown in Figure 6. Room temperature response is measured at over 1400 V/W, with a signal-to-noise ratio of 43.1 dB. The device is used in an application which requires a 40 Hz response rate.

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Figure 6. Device response.