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Flexible active-matrix cells with selectively poled bifunctional polymer-ceramic nanocomposite for pressure and temperature sensing skin

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A monolithically integrated bifunctional frontplane is introduced to large area electronics. The bifunctional frontplane element is based on a composite foil of piezoelectric ceramic lead titanate nanoparticles embedded in a ferroelectric poly(vinylidene fluoride trifluoroethylene) polymer matrix. Bifunctionality to pressure and temperature changes is achieved by a sequential, area selective two-step poling process, where the polarization directions in the nanoparticles and the ferroelectric polymer are adjusted independently. Thereby, sensor elements that are only piezoelectric or only pyroelectric are achieved. The frontplane foil is overlaid on a thin-film transistor backplane. Our work constitutes a step toward multifunctional frontplanes for large area electronic surfaces. © *2009 American Institute of Physics*. [DOI: 10.1063/1.3191677]

I. INTRODUCTION

In large area electronic surfaces a transistorized backplane drives a frontplane, which provides the specific functionality.[1] While architecture and backplane technology follow the flat-panel display model, many frontplane functions beyond displays are in active research.[2] Recent frontplane demonstrations include arrays of pressure and temperature sensors on organic transistor backplanes,[3,4] and flexible piezoelectric and pyroelectric sensors integrated with field effect transistors.[5,6] Such piezo- and pyroelectric sensor systems[5,6] simultaneously react to temperature and pressure changes, making discrimination between temperature and pressure changes impossible. Sensors that show both piezo- and pyroelectricity can thus be used only in experiments where one parameter, either temperature or pressure is kept constant. One long-range goal for electronic surfaces is electronic skin, an electronic system of compliant transducer circuits covering large areas and conformable of three-dimensional objects. Moving toward electronic skin requires the introduction of several collocated frontplane functions, in particular the sensing of pressure and temperature. We show that such frontplanes are feasible by designing a nanocomposite material made of ceramic ferroelectric nanoparticles embedded in a polymeric ferroelectric matrix.

II. SENSOR DESIGN

The ferroelectric polymer matrix ensures the mechanical flexibility to the sensor frontplane. Using a two-step poling sequence, the composite's inherent sensitivity to pressure and temperature can be selectively and spatially controlled, and therefore allows for two distinct sensory modes from a single material. A bifunctional sensory cell is made of two (one pressure-sensitive, and one temperature-sensitive) subcells. Cross-sensitivities between the subcells are minimized by appropriate formulation and poling. This bifunctional sensor array (frontplane foil) is then aligned with thin-film transistors (TFTs) on a flexible backplane. Each sensory subcell is interfaced with a single transistor. The resulting subcells are shown to be sensitive to either pressure or temperature, with minor cross-sensitivity to the other input parameter. Figure 1(a) illustrates the scheme of the bifunctional frontplane, where the temperature sensitive, pyroelectric element has a parallel orientation of the polarization in the ceramic nanoparticles and ferroelectric polymer matrix, while the pressure sensitive, piezoelectric element has an antiparallel orientation of the polarization. The frontplane is laminated with two transistors of the backplane, one for the pressure and one for the temperature sensor, which convert the charge generated by the sensor elements to an output current. Both sensor elements are described by the same equivalent circuit scheme shown in Fig. 1(b). Here the transistors gate voltages V_G are adjusted to set the working point of the field effect transistors. The gate resistance R_G isolates the high impedance sensor elements from the gate bias voltage source. This ensures open circuit conditions for the sensor elements when pressure or temperature transients are measured at times shorter than the *RC* time constant of the subcell (defined by the gate resistance R_G, the input impedance of the transistor R_I, the capacitance C_S of the sensor cell, and the gate capacitance C_G of the transistor). The piezo- or pyroelectric ele-

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