High-Resolution Temperature Sensing with Source-Gated Transistors

R. A. Sporea, J. M. Shannon, S. R. P. Silva

Advanced Technology Institute, FEPS, University of Surrey, Guildford, Surrey, GU2 7XH, U.K.

email: r.a.sporea@surrey.ac.uk; phone: +44 1483 686083

Source-gated transistors (SGTs) [1] are three-terminal devices in which the current is controlled by a potential barrier at the source. The gate voltage is used primarily to modulate the effective height of the source barrier. These devices have a number of operational advantages over conventional field-effect transistors, including a potentially much smaller saturation voltage and very low output conductance in saturation, which lead to low power operation and high intrinsic gain [2].

Thin-film SGTs with Schottky source barriers have been fabricated on glass, in a self-aligned, back-gate polysilicon process. A microphotograph of a typical SGT is shown in Figure 1, while Figure 2 shows schematically the cross-sectional structure of a device (processing described in [2]). Electrical measurements (Figure 3) reveal on/off ratios in excess of 10^5 and typical SGT behaviour: small change in saturation voltage with gate potential and flat output characteristics in the saturation regime up to relatively high drain voltages. These devices seem to be well suited for signal amplification applications and as active loads in large area electronic circuits, and represent the experimental basis of the current study.

A feature of devices containing Schottky barriers in general and of the Schottky SGTs in particular is the temperature dependence of the drain current; high Schottky barriers produce a large variation of drain current against temperature, which is undesirable in most applications. In order to keep the current variation with temperature small, low barrier heights have to be used. However, the very large activation energy which can be obtained by designing the SGT with a high Schottky barrier can be exploited for highly sensitive temperature measurements.

In order to act as a temperature sensor, the SGT can be operated at a constant gate voltage, to produce an exponentially temperature-dependent drain current, or at constant drain current in a feedback loop, leading to a

change in gate voltage with temperature given by: $\frac{\partial V_G}{\partial T} \approx \frac{1}{T} \left(V_G - V_T - \frac{t_s \phi_B (C_i + C_s)}{\alpha C_i} \right)$, where t_s is the

semiconductor thickness, α is the barrier lowering constant, ϕ_B is the height of the source barrier at zero applied bias, V_T is the threshold voltage, C_i and C_s are the capacitances per unit area of the gate insulator and semiconductor, respectively. The constant V_G operation can be applied to a sensing scheme such as [3] and can make use of the high intrinsic gain of the SGT [2], while a (linearly) temperature dependent gate voltage scheme can be integrated into a sensor of the type described in [4]. Figure 4 shows the change of V_G with temperature for two devices (low and high barrier) operated at constant current. A simulation of a similar structure with a high barrier (Figure 5) reveals a $1/T$ dependence of V_G . From both the measurements and the simulation it can be concluded that devices with high barriers exhibit a very strong sensitivity of V_G to temperature (several $100\text{mV}/^\circ\text{C}$), which is far more than that of typical p-n junctions used in integrated temperature sensors ($\sim 2\text{mV}/^\circ\text{C}$) and could translate into greatly improved resolution when measuring small changes in temperature. Figure 6 describes the measured linear dependence between sensitivity and gate voltage which is in accordance with the equation above. As the threshold of the SGT can be set during the design phase [2], highly sensitive SGTs can be made which have a very negative V_T and operate at low V_G to meet the requirements of low voltage systems.

Source-gated transistors are inherently very stable under electrical stress, as has been described in [5]. Figure 7 shows the excellent stability of the drain current over a number of days in a fabricated polysilicon SGT, together with the very small threshold shift due to stress. This behaviour, together with the low saturation voltage and high output conductance is very desirable for low power, sensor matrices where power supply ripple rejection, uniformity of signals across a wide area, sensitivity and power are important design considerations. The versatility of the SGT concept is extended by the possibility of realizing, in principle, of an SGT structure in any semiconductor or fabrication process as long as a reliable potential barrier can be fabricated at the source.

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Fig. 1. Micrograph of self-aligned polysilicon SGT. Width $W=50\mu\text{m}$, source length $S=2\mu\text{m}$, source-drain separation $d=10\mu\text{m}$.

Fig. 2. Cross-section of the self-aligned structure.

Fig. 3. Output characteristics (left) and corresponding transfer curve (right) for an SGT with high source barrier and $W=50\mu\text{m}$, $S=2\mu\text{m}$, $d=6\mu\text{m}$.

Fig. 6. Measured dependence of dV_G/dT on V_G as temperature changes.

Fig. 4. Measured variation of the gate voltage with temperature for SGTs with low (left) and high (right) barriers operated at constant current.

Fig. 5. Simulation of change in gate voltage with temperature for a Schottky barrier SGT operated at constant current. Left to right: $I_D=3\text{nA}$, 10nA , 30nA , 100nA , 300nA , $1\mu\text{A}$, $3\mu\text{A}$.

Fig. 7. a) Stability of drain current to prolonged electrical stress for polysilicon SGTs; b) Change of transfer characteristic during stressing period.