Stand-alone Piezoeletronic Transistor

J. B. Chang, H. Miyazoe, M. Copel, P. M. Solomon, X.-H. Liu, T. M. Shaw, A. G. Schrott, G. J. Martyna, D. M. Newns
IBM T.J. Watson Research Center, 1101 Kitchawan Rd, NY 10598
josechan@us.ibm.com

Concerns about the rapidly increasing power requirements of modern computing are driving research into novel high speed, low power, low voltage logic switches. Here, we report on the first physical realization of a stand-alone, monolithically integrated PiezoElectronic Transistor (PET), a new computer switch which could potentially operate conventional computer logic at 1/50 the power requirements of Si-based transistors[1,2]. This device requires a piezoelectric (PE) and piezoresistive (PR) element pair to be mechanically clamped together, allowing free movement at the PE/PR interface while minimizing mechanical motion at other boundaries. Here, we present an innovative device structure which has enabled for the first time a proof-of-concept stand-alone PET demonstration, including PZT (PbZr0.52Ti0.48O3) PE and SmSe[3] PR elements held together by a drum clamp suspended over an airgap (Fig 1).

We use ANSYS Mechanical simulation of a simplified device structure to investigate the expected behavior of the stand-alone PET and to guide device design. The target PZT device, based on realistically achievable dimensions and an SmSe thickness of 30nm, is predicted to have I_{off} ~10^{-8}A and I_{on}/I_{off} ~ 10 at V_{gate}= 10V. Modeling results further outline a path towards future device improvement by using a PE material with larger piezoelectric response such as PMN-PT and by thinning the PR and barrier layers. The fabrication process flow and TEM of the completed PET structure are shown in Fig. 2 and 3. Despite ~20nm rms surface roughness in the starting PZT film, a 40nmx40nm nail can be clearly seen within a 30nm airgap. The transfer and output characteristics of a stand-alone PET (Fig 4) demonstrate an I_{on}/I_{off} of ~1.5. The transfer characteristics are noisy, indicating an as yet unknown source of instability in the device as the PE is actuated.

For the first time, we have built a stand-alone, monolithically integrated piezoelectronic transistor. A novel device structure designed to enable PET device fabrication under realistic processing constraints was proposed, simulated, fabricated, and measured to have I_{off} of ~10^{-7} and I_{on}/I_{off} of 1.5 at V_{gate}=20V, consistent with ANSYS predictions when device non-idealities are taken into account. By switching from PZT to PMN-PT and optimizing device dimensions, we predict that this novel PET structure can be extended to achieve operation

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[1] D.M. Newns et al, Adv. Mat., vol. 24, pp. 3672-3677, 2012.
[2] D.M. Newns et al, J. Appl. Phys., vol. 111, pp. 084509.1-18, 2012.
[3] M. Copel, et al., Nano Lett., vol. 13, pp. 4650–4653, 2013.

with an I_{on}/I_{off} of 10^4 at V_{gate}=5V.

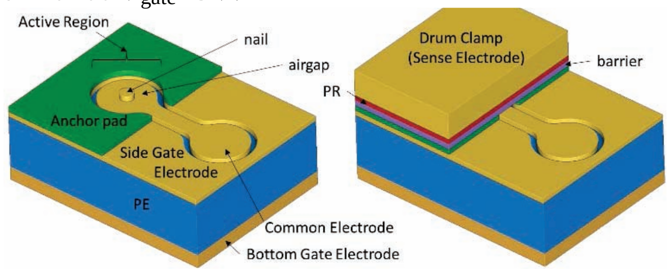

Figure 1: Stand-alone PET device. Control voltage is applied between side/bottom gate electrodes and common electrode to move active region up and down. A nail translates PE motion into pressure applied to the PR film, which modulates resistance of PR in output current path. Output current flows from common electrode through nail, PR, and out through the drum clamp, which acts as the sense electrode.

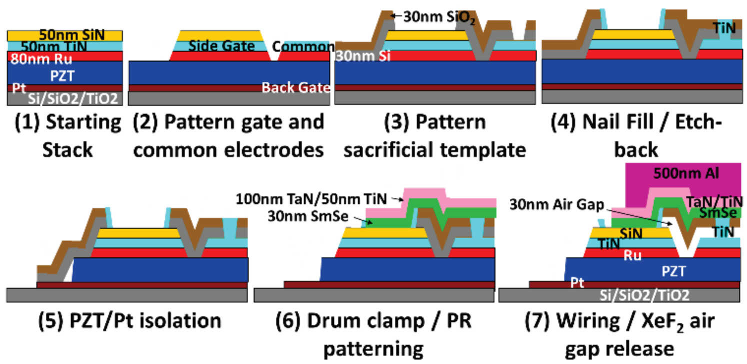

Figure 2: PET device fabrication process flow

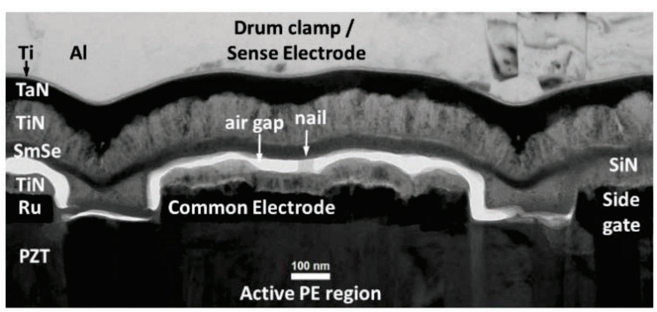

Figure 3: TEM of stand-alone, monolithically integrated PET device.

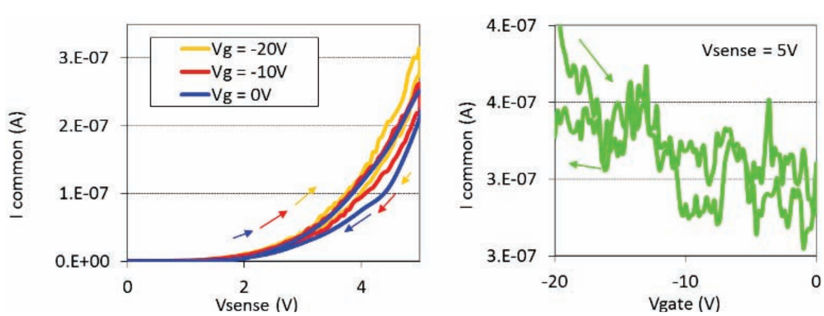

Figure 4: Output and transfer characteristics. Stand-alone, monolithically

integrated PET device with 10μm active PE diameter and 200nm nail diameter.