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Low Power, High Speed, and Mixed-Signal Tunneling Device Technology

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As discrete zero-bias tunnel diode detectors move toward applications in millimeter wave cameras[1], new tunnel diode/transistor circuit opportunities and new prospects for utilizing tunnel transistors are emerging. For example, adding two clocked tunnel-diode pairs to the output ports of a differential amplifier[2,3] enables approximately 4× reduction in power dissipation without reducing speed compared to transistor-only comparators. Circuits of this type form the core of direct digital synthesizers at frequencies in the range of 100-200 GHz.

The series combination of a tunnel diode with an inductor provides a low-power frequency up-converter[4]. A digital input bit stream at low frequency (e.g. 100 MHz) biases the tunnel diode into its negative differential resistance region. On biasing into this region, the tunnel diode oscillates at the desired carrier frequency (GHz), thus a two-element circuit can provide a direct up-conversion. A new heterojunction bipolar transistor and resonant tunneling diode configuration of this up-converter adds isolation and gain. Self-aligned processes for integrating InP-based tunnel diodes and transistors are now being developed which utilize silicon nitride sidewall spacers to set the emitter-base separation.

In a field-effect transistor, the minimum voltage swing needed to turn a transistor from on to off is a key figure of merit, which ultimately determines how low in power a device technology can be. The MOSFET subthreshold swing is limited by $(kT/q)\ln 10$, or 60 mV/decade at room temperature. With continued device scaling the subthreshold swing rises so methods for achieving lower subthreshold swing are needed. Through an analytic analysis it can be shown that the subthreshold swing of interband tunnel transistors can be less than 60 mV/decade[5]. This analysis suggests new transistor configurations for low subthreshold swing. Processes for forming tunnel junctions in Si are being explored[6,7].

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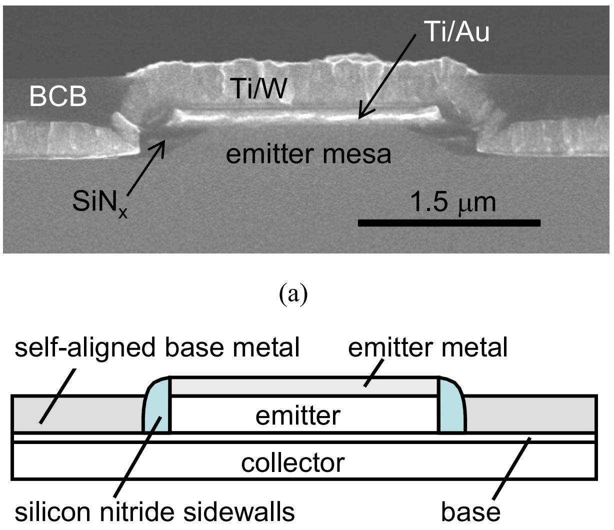

(a)

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Fig. 1. Self-aligned heterojunction bipolar transistor process using nitride sidewalls: (a) micrograph taken before reactive ion etching to remove the Ti/W from the Ti/Au emitter and (b) schematic cross section of the base emitter junction.

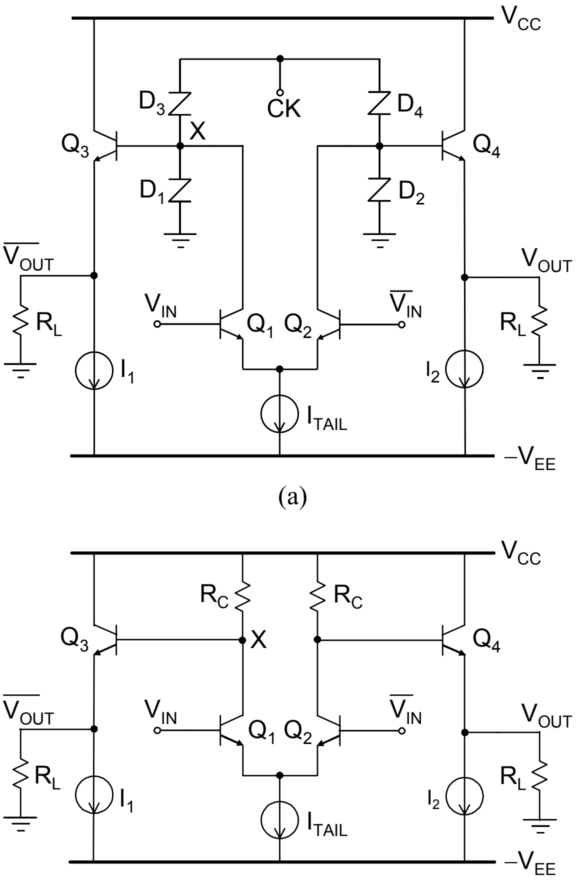

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Fig. 2. Differential comparators: (a) tunnel diode/transistor and (b) transistor-only circuits.

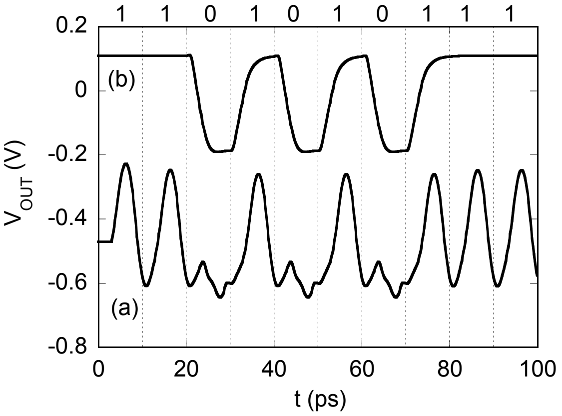
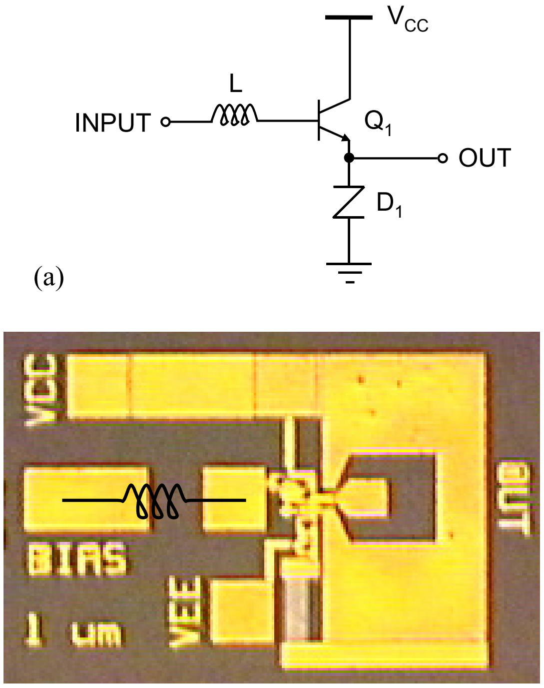


Fig. 3. Simulated output waveforms for the two circuits of Fig. 2: (a) tunnel diode/transistor and (b) conventional comparator.



(a)

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Fig. 4. Tunnel diode/transistor frequency translator: (a) schematic and (b) micrograph, 0.55 × 0.75 mm.

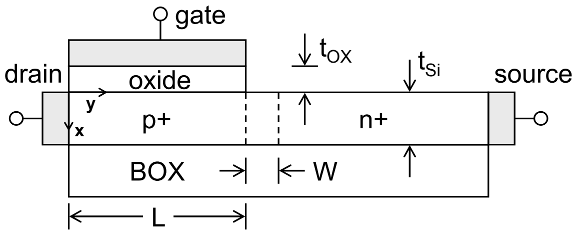

Fig. 5. Ultrathin body Si-based interband tunnel transistor; the gate is placed over the fully-depleted *p*-side and the transistor is operated in the Zener tunneling direction. Subthreshold swing less than 60 mV/decade is possible in interband tunnel transistors.