110-GHz Monolithic Resonant-Tunneling-Diode Trigger Circuit

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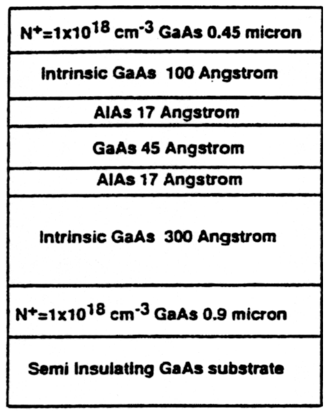
Abstract—**Resonant-tunneling diodes (RTD's) with large peak current densities have been monolithically integrated with resistors to form trigger circuits. A new RTD trigger circuit has been used at 110 GHz with subpicosecond timing jitter.**

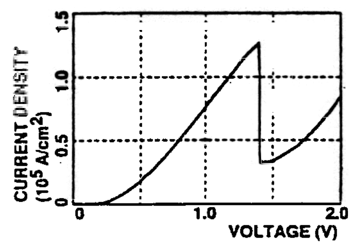
RESONANT-tunneling diodes (RTD's) have long been considered as very promising devices for high-frequency applications. Recent experiments have verified this promise. For example, RTD's have been used to build microwave oscillators with oscillation frequencies in excess of 700 GHz [1]. Triggering up to 60 GHz has also been demonstrated using RTD's [2].

In this paper, we report the design and fabrication of a new RTD structure to be used in a monolithically integrated trigger circuit. The new structure has been designed to have high peak current densities with relatively low resonant voltages. These devices have been monolithically integrated with resistors to build a new high-frequency trigger circuit. This circuit has been shown to have subpicosecond timing jitter and operating frequencies up to 110 GHz.

RTD's are well known for their quantum mechanical transport mechanisms. Quantum mechanical techniques have been successfully used to simulate static current–voltage characteristics of these devices [3]. But, when it comes to high-frequency operation, RTD's are still limited by conventional *RC* time constants [4]. Therefore, maximizing the peak current density and minimizing the capacitance per unit area have been the key features of our recent work [5]. However, our previous devices had peak current densities of 1.25×10^5 A/cm^2 with resonant voltages as high as 3 V. Such a large power dissipation resulted in thermal instability for large-area diodes. All devices with areas larger than 30 μm^2 burnt out in a few seconds after biasing around the peak voltage. In order to solve the heating problems, we designed a new RTD structure (Fig. 1(a)). The new structure was similar to the previous one [5], but had a shorter spacer layer of 300 Å compared to the previous 700-Å layer. The double-barrier region had thin (15 Å) AlAs barriers, already proven to yield high peak current densities. The current density versus voltage characteristic of the new structure at room temperature is shown in Fig. 1(b). These new devices had resonant voltages close to 1.4 V and even the largest area diode, which has a 80-μm^2 area and a 100-mA peak current, was found to be thermally stable.



(a)



(b)

Fig. 1. (a) Schematic of the epilayer design for the high-current-density RTD structure. (b) Current density versus voltage characteristic of the RTD structure at room temperature.

Monolithic integration of any high-frequency device with other circuit elements is essential, as hybrid connections tend to slow down the overall device performance. That was why we chose a microwave-compatible planar process in which we monolithically integrated the RTD's with the resistors. The fabrication consisted of defining the active device area through etching and proton isolation. Conductive epilayers were used as resistors, defined during the proton isolation step. The RTD's and resistors were interconnected by using coplanar transmission lines. Coplanar transmission lines were also fabricated, with probe pads to access input and output signals. This overall approach has resulted in successful fabrication of monolithic RTD integrated circuits.

A recent paper investigated the pulse forming and triggering performance of a single RTD [2]. For pulse forming, a large-amplitude sine waveform was applied to the RTD, so that we could get repetitive switching. This resulted in a large feedthrough component at the output. For triggering, we applied the sum of a high-frequency (HF) sine waveform and

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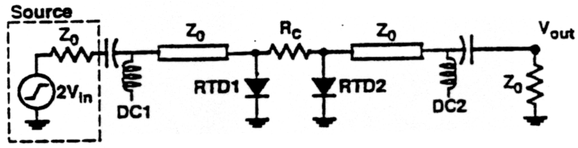

Fig. 2. Circuit schematics of the two-diode RTD trigger circuit.

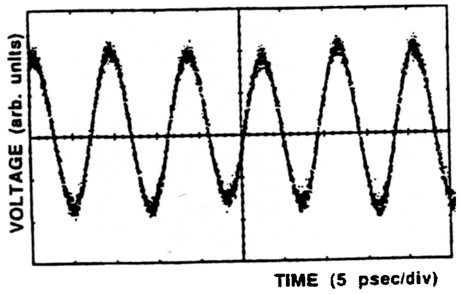

Fig. 3. Oscilloscope trace of a 110-GHz signal triggered by the output of the RTD trigger circuit.

a slowly rising ramp to the RTD. This resulted in switching of the RTD whenever the voltage on the device reached the resonant voltage. As the ramp signal was slowly increasing, the timing of the switching was determined by the maxima of the HF signal; and, as the RTD switched, a voltage step synchronous with the HF waveform was formed. This scheme had a smaller feedthrough component as the amplitude of the input HF signal is 30 times smaller than the pulse forming scheme. The resulting voltage step was then used to trigger off the same HF signal in a digital scope. Although trigger performance up to 60 GHz was achieved, this combination was limited by the timing jitter. In this combination, switching of the RTD occurred around a maximum of the HF sine waveform, where the slope was a minimum. This translated as a maximum timing uncertainty in the switching event, so that the resulting voltage pulse had a maximum timing jitter. Such a timing jitter severely limits higher frequency operation.

To overcome this jitter problem we have pursued a two-diode approach. Previously, a similar approach based on hybrid connections of Esaki tunnel diodes was shown to have operating frequencies up to 18 GHz [6]. Using the fabrication process described, we have monolithically integrated a circuit consisting of two RTD's and a resistor. The circuit is connected to outside elements through coplanar transmission lines, as shown in Fig. 2. Microwave probes were used to apply the input signal and to extract the output signal.

High-frequency experiments were performed by applying the sum of a ramp and a high-frequency (HF) sine waveform as the input signal. As explained before, such an input forces the first diode (RTD1 in Fig. 2) to switch near one of the maxima of the HF signal. This switching results in a voltage step produced across the second RTD (RTD2 in the figure), which results in an instant increase on the bias of RTD2. If the dc input to the second diode is chosen appropriately, this instant bias change will bring the bias voltage of the RTD2 just below peak voltage. Then, when the HF signal reaches the maximum slope, the total voltage on the RTD2 exceeds the peak voltage and the RTD2 is forced to switch. Although the switching of the RTD1 has a larger timing jitter, this switching ends before RTD2 switches. As RTD2 switches when the input signal goes through the maximum slope, this translates as less timing uncertainty for the switching step that was produced by RTD2, when compared to switching around a maximum of the HF signal. The voltage step produced by RTD2 is now synchronous with the HF signal and, as it has lower jitter, it may be used for triggering at higher frequencies.

We have tested this principle using HF signals at W-band frequencies (75–110 GHz). Signals were obtained by using microwave synthesizers and W-band waveguide multipliers. We used a W-band to V-band (50–75 GHz) adapter and a microwave probe with a V-band input to apply the signal to the circuit. Such a lossy scheme has resulted in a typical -15-dBm W-band signal level at the input of the trigger circuit. A 3-V amplitude ramp signal at 60 MHz with a dc bias for RTD1 was applied through the bias input of the microwave probe. RTD2 was biased from the other end of the circuit through another microwave probe which was also used to extract the switching step as the output signal. Both RTD1 and RTD2 had 60-μm^2 areas and 75-mA peak currents. An 80-Ω resistance value was chosen for the resistor R_c. The output signal was then applied to the trigger input of a Tektronix CSA803 waveform analyzer which carried a SR-32 sampling head. The input of the sampling head was fed with the output of another W-band multiplier, which shares the same microwave synthesizer with the first W-band multiplier. Then, we tried to observe the HF signal on the waveform analyzer. Fig. 3 shows a measured 110-GHz waveform. This is at a frequency six times higher than previously obtained with trigger circuits using Esaki tunnel diodes. Jitter measurements of the observed signal have also been made using the waveform analyzer, with 1000 samples recorded in 60 s. As little as 0.75-ps timing jitter was observed. Most of this timing jitter was introduced externally by the waveform analyzer and the high-frequency synthesizers, showing that our trigger circuit has timing jitter in the range of hundreds of femtoseconds.

In summary, we have designed and fabricated RTD's with high peak current densities and low resonant voltages. These RTD's were monolithically integrated with resistors to build trigger circuits. Experiments demonstrated triggering performance up to 110 GHz with subpicosecond timing jitter.

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