Ultrafast Differential Sample and Hold Using Low-Temperature-Grown GaAs MSM for Photonic A/D Conversion

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***Abstract*—This letter demonstrates an ultrafast sample and hold circuit using optically triggered metal–semiconductor–metal switches made of low-temperature-grown GaAs for use in a photonic analog-to-digital conversion system. A differential configuration is incorporated to reduce feedthrough noise.**

***Index Terms*—Analog-to-digital conversion, low-temperature-grown GaAs, metal-semiconductor-metal devices, optical data processing, sample-and-hold circuits.**

I. Introduction

WITH DIGITAL technologies dominating the marketplace along with the advancement of corresponding signal processing techniques, high-speed analog-to-digital (A/D) converters are becoming more critical in the areas of microwave communications and radar. Various GaAs- and InP-based circuits have achieved several gigasample per second sampling rates at lower resolutions [1]–[3]. Superconducting A/D systems have shown promise for high- resolution conversion at slightly slower speeds [4]. Despite these breakthroughs, the performance improvement of electrical A/D converter technologies has been unable to meet the demand for faster sampling rates [5].

One of the fundamental constraints limiting the performance of electrical A/D converter technologies is the aperture jitter caused by clock jitter and sampling gate variation [5]. As a solution, the idea of combining the low jitter and high-speed advantages of photonics with electrical A/D converters in a hybrid system has spawned a number of photonic A/D conversion systems in recent years [6]–[8].

Many of these proposed photonic A/D conversion systems consist of an input electrical signal biasing an optical modulator whose output is optically demultiplexed to an array of electrical A/D converters [6], [8]. However, the speed and linearity of the optical modulator often times limit the performance of these systems.

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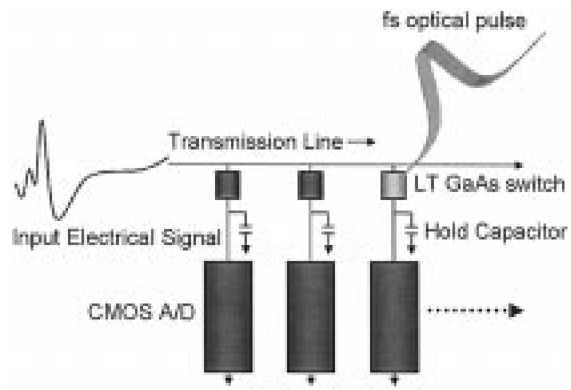


Fig. 1. Schematic of proposed A/D conversion system.

To circumvent this problem, we propose an electrical sample and hold scheme utilizing low- temperature (LT)-grown GaAs metal–semiconductor–metal (MSM) switches. Fig. 1 shows a schematic of our proposed A/D conversion system. Optically triggered by a short-pulse laser, the switch would be attached to a transmission line and would sample the input electrical signal onto a hold capacitor at a rate equal to the pulse repetition rate. An electrical A/D converter would then extract this sampled data. By time interleaving N of these channels, the aggregate sampling rate becomes $N\times$ the single electrical A/D converter sampling rate. In this way, the bandwidth and timing constraints of high-speed sampling are placed only on the input sample and hold circuit, freeing the electrical A/D converters to operate at much slower speeds. In addition, the sample and hold scheme allows the switch to be nonlinear, only placing requirements on the speed and responsivity of the device. The short lifetime and relatively high mobility of LT-grown GaAs create a short sampling gate enabling high-speed sampling with reasonably good resolution [9].

In this letter, we demonstrate a sample and hold circuit using optically triggered MSM switches made of LT-grown GaAs. The circuit achieves a sampling gate width of 1.5 ps and exhibits 5.7 effective number of bits (ENOB) under dc input conditions.

One potential drawback of the sample and hold circuit is capacitive feedthrough from the input signal corrupting the sampled voltage on the hold capacitor. We resolve this issue with a differential device configuration.

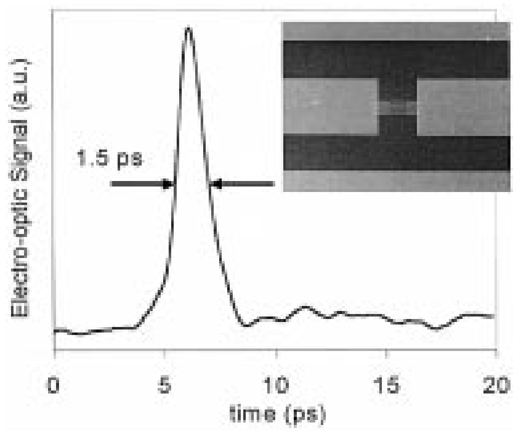


Fig. 2. Switch response for a 2-μm finger spacing MSM. Sample was grown at 250 °C and annealed at 800 °C for 1 minute. Inset is scanning electron micrograph (SEM) image of the switch and transmission line.

II. Experiment

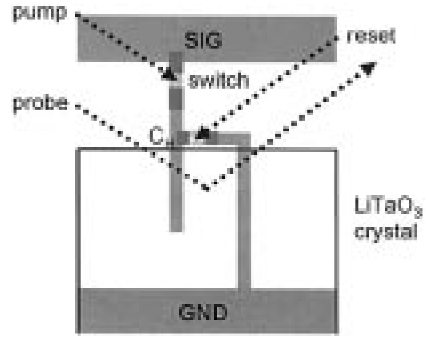
A. Switch Response

The switch response was measured by placing the MSM in the middle of a coplanar waveguide transmission line structure (inset, Fig. 2). A titanium/gold contact was deposited on top of the LT GaAs substrate for both MSM and transmission line patterns. The MSM was dc biased and optically triggered with a ~150 fs full-width at half-maximum (FWHM) pump pulse, launching electrical transients down the transmission line. These transients were measured by time-resolved electrooptic sampling [10], using a lithium tantalate electrooptic crystal placed on top of the transmission line. The ultrafast response (1.5 ps FWHM) of the switch is evident (Fig. 2). Different speeds and responsivities were obtained by varying growth temperature, postgrowth anneal conditions, and the MSM pattern.

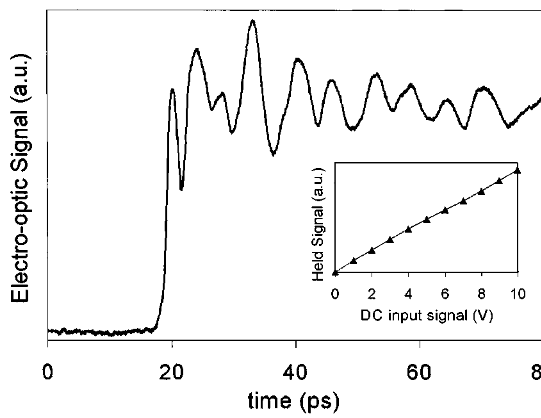
B. DC Sample and Hold

The sample and hold test circuit was made by attaching the MSM switch and hold capacitor (C_H) in series across the signal and ground lines of a transmission line [Fig. 3(a)]. A titanium/gold contact was used for the entire pattern. Different MSM patterns were used to vary the switch, as well as the hold capacitor.

When the switch is optically pumped, photoexcited carriers charge up the hold capacitor to the input voltage level with a time constant $= R_\mathrm{switch}C_\mathrm{H}$. As long as the time constant is short enough, accurate ultrafast sampling is achieved despite a nonlinear switch. Time-resolved electrooptic sampling was used to measure the voltage across the hold capacitor as the MSM switch was turned on. A dc input signal was initially sampled. A lithium tantalate crystal was placed on top of the metal lines probing the ends of the hold capacitor, enabling the held voltage to bias the crystal as seen in Fig. 3(a). Due to the repetitive nature of the pump probe measurement, the hold capacitor was reset by triggering the hold capacitor MSM with a pulse train synchronized to the pump and probe pulses. A typical measurement result is given by Fig. 3(b). We believe some parasitic inductance (~200 pH) in the test pattern causes the oscillations of the signal. This ringing eventually dies off, leaving the signal at a constant offset. The inset of Fig. 3(b) shows the held output signal [step height of Fig. 3(b)] as a function of the dc input signal for one particular sample and hold device. The held output signal was taken 100 ps after the leading edge of the step to avoid effects from ringing. The pump pulse triggering the switch was set at ~0.2 nJ for all measurement points. The linearity of the graph confirms the accuracy of the sample and hold process, exhibiting 5.7 ENOB for the input voltage range given.



(a)



(b)

Fig. 3. (a) Sample and hold test pattern. A Lithium Tantalate crystal was placed on top of the two metal lines probing the hold capacitor voltage. (b) Sample and hold of dc input signal. Sample was grown at 250 °C and annealed at 800 °C for 1 minute. Inset shows the held output signal as a function of dc input signal.

C. Differential Sample-and-Hold Device

Due to the parasitic capacitance of the MSM switch, the sample and hold circuit forms a capacitive voltage divider. Thus, fluctuations in the input signal feedthrough to the hold capacitor and corrupt the held signal. To eliminate this feedthrough noise, we adopt a differential configuration device. Fig. 4 shows the differential sample and hold test pattern. The symmetry of the device makes the feedthrough equal on both hold capacitors. The sample and hold is performed on the left side of the pattern, while the right side of the pattern serves as a dummy device that tracks the feedthrough voltage. By taking the differential signal between the hold capacitor voltages, the feedthrough is cancelled out. We demonstrate this scheme by measuring the voltage across each hold capacitor, as well as the differential voltage between them as a function of time. Placement of the probe pulse for each voltage measurement,

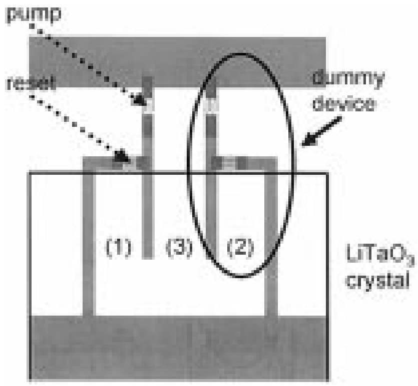


Fig. 4. Differential sample and hold test pattern. Numbers indicate position of probe pulse for corresponding curves in Fig. 5.

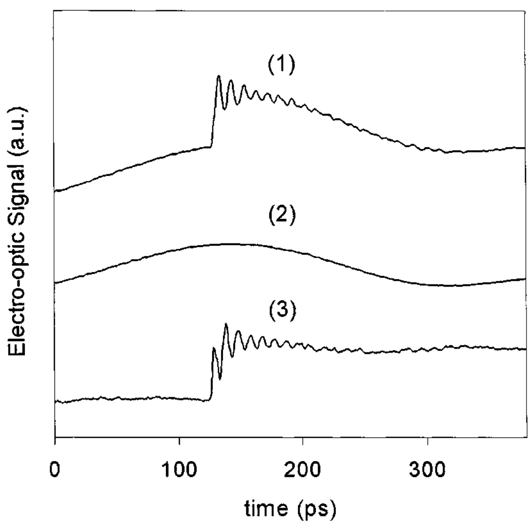


Fig. 5. Electrooptic sampling measurement results for differential sample and hold test circuit. Numbers indicate data for corresponding probe pulse positions in Fig. 4. (1) Feedthrough plus held voltage. (2) Feedthrough only. (3) Held voltage with reduced feedthrough due to differential detection.

along with the corresponding output signal is shown in Figs. 4 and 5, respectively. The top trace shows the feedthrough noise plus the held voltage on the left-hold capacitor, the middle trace shows the feedthrough noise being tracked by the right-hold capacitor, and the bottom trace shows the differential signal. The third trace clearly indicates a reduction in the feedthrough noise. The residual feedthrough noise seen is likely a result of the electrooptic crystal having a finite thickness, leading to the detection of extraneous electric fields unrelated to the hold capacitor voltage. Numerical subtraction of (1) and (2) leads to increased reduction of feedthrough noise.

III. Conclusion

We successfully demonstrate the cancellation of feedthrough noise using a differential sample and hold circuit with LT GaAs MSM switches. The circuit achieves a sampling gate width of less than 2 ps and exhibits 5.7 ENOB under dc input conditions. Future testing will include multiple sampling of dynamic inputs in order to measure the bandwidth and resolution limits of the sample and hold circuit. Variation of growth and post-growth anneal conditions will provide additional parameters to improve the performance of the device. Judging from these prospects in addition to the results presented, we believe this circuit is a promising candidate for use in future high-speed photonic A/D conversion systems.

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