Transmission Line Optimization

Travis Butler[1], Amal El-Ghazaly, Ph.D.[2], and Professor Jeffrey Bokor[2]
[1] Department of Computer Engineering, Jackson State University;
[2] Department of Electrical Engineering and Computer Science, University of California, Berkeley

***Abstract*—GdFeCo has been shown to switch its magnetization direction at extremely fast rates and with just optical excitation, and more recently with electrical excitation [1]. This project optimizes transmission lines that may be able to show ultrafast electrical switching of a single nanodot down to the size of 50nm. To do this, an Auston switch is fabricated into a transmission line on an LT-GaAs substrate. A laser pulse is shined onto the switch to generate an ultrafast photocurrent pulse, which propagates down the transmission line [1]. The pulse was measured at different points along the line and found to have a FWHM of 54.7ps before the taper, 54ps after the taper, and 51.6ps at the end of the transmission line. Although the pulse widths are wide, the nanoscale tapered region was found to not affect the pulse shape and therefore can be used to effectively drive electrical pulses to nanoscale dots in the future.**

***Index Terms*— Transmission Line, Ultrafast Electrical Switching, Picosecond Pulses**

I. Introduction

To achieve higher computing speeds while expanding the shelf life and decreasing the energy consumption of electronics, the optimization of transmission lines and the improvement of electrical switching is required. Recently, experiments have measured an electrical pulse as small as 9ps on coplanar strip-lines, or CPS [1]. This electrical pulse was shown to switch the magnetization of a GdFeCo magnetic dot of size 5 um. To prove the efficiency of electrical switching, the size of the nanodot must be down-sized.

In this research, we hope to optimize transmission lines to drive a pulse of width between 2-4ps to gain consistent electrical switching on nanodots down to the size of 50 nm. To demonstrate the picosecond performance, we used transmission lines fabricated on top of LT-GaAs with Auston switches and the photoconductive element, as was done in [2]. The geometry of the gap and transmission line structure can also affect the overall speed and width of the pulse, but this can be minimized [3]. Before the actual measurement of the electrical pulse width and the electrical switching, we measured the leakage current of each transmission line's Auston switch to test whether it was shorted or not. After finding a working sample, we aligned the laser to get an accurate pulse width. By doing this, we were able to measure the pulse width at different positions down the line.

II. Fabrication Process of transmission lines

In the fabrication process of transmission lines, we begin with a commercial substrate of 300µm of GaAs, 50nm of AlAs, and 1µm LT-GaAs, ordered bottom to top. We then used four "lift-off" processes to create the different parts of the transmission line. These "lift-off" processes create the MgO insulation layer, the Ti/Au wide transmission line, the Ti/Au narrow transmission line, and finally, the GdCo nanodot at the center of the crossbars of the transmission line.

III. Experimentation

Once the samples are prepared, we identify the working devices by testing them on the probe station and by measuring the dark and photo-currents. If the probe read a steady current, the sample was shorted, meaning that the interdigitated electrodes of the Auston switch were touching or there was leakage through the semiconductor due to a defect in the MgO insulation layer. If the probe read zero current (or just noise), the sample could be a working device. The second way to test the sample was through measuring and comparing the dark current versus the photocurrent from the Auston switch. The dark current should be extremely low in comparison to the photocurrent if the sample is to be considered a working device. Shining the laser on the Auston switch generates electron-hole pairs. Then, when a voltage is applied across the Auston switch, a current is generated. After finding working samples, we used a time-resolved, pump-probe measurement to determine the pulse shape as the pulse propagated down the transmission line. To do this, we shot the pump laser beam onto the Auston switch and the probe laser beam at a detector farther down the transmission line. The detector tip was then moved to different positions along the transmission line and used to measure the width of the pulse in time, as it propagated down the line.

IV. Results and discussion

The results of this experiment show the optimization of transmission lines designed to contact down to nanoscale loads. By first testing the Time Domain Thermal Reflectance (TDTR), we were able to view the ideal scenario for the minimum pulse width provided by the LT-GaAs. For the substrate used in this work, we measured a full width at half max (FWHM) of approximately 3ps, which represents the best possible pulse width a device made on this substrate can achieve. While taking measurements before the taper, after the taper, and at the end of the transmission line using a detector tip, we were able to see the transient behavior of the electrical pulse as it propagated on two transmission lines, Short33N and Thru33N. However, our central focus was on Thru33N, in which we observed a pattern of reflections. By measuring the sample at various positions along the transmission line, we determined that there were no new reflections comparing before or after the taper. Considering impedances at the Auston switch and the detector

.

tip, we determined the reason for the reflections as well as the change in polarity of the pulse. We conclude that the end of the transmission line with the detector tip appears as a short, while the end with the Auston switch appears as an open.

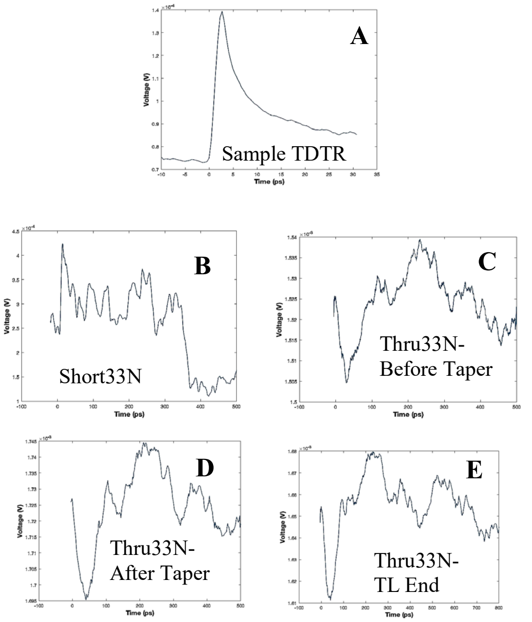
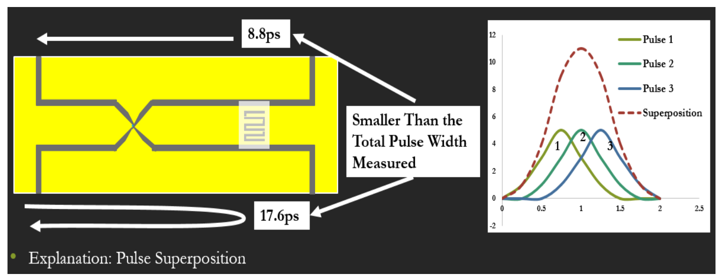


Figure 1 shows the pulses measured in the experiment. 1A is the pulse measured from the semiconductor material. 1B is the pulse measured on the Short33N sample. 1C, D, and E are the pulses measured on the Thru33N sample at various positions along the TL.

We centered our focus on transmission line optimization. We tested two transmission lines on our sample. The first one was Short33N. In a couple of our measurement, we were given a similar shape in pulse as Figure 1A, shown in Figure 1B. This transmission line, however, had numerous reflections which proved to be noisy and difficult to analyze. As a result, we focused on the analysis of pulse propagation along the transmission line Thru33N. Thru33N also resulted in similar pulse shapes as in Figure 1A, shown in Figures 1C, 1D, and 1E, however, there were three issues. The first issue is that the pulse width was not between 2-4ps. To understand how much broadening of the pulse occurred on the transmission line itself, we measured Thru33N three times at three various locations, before the taper, after the taper, and at the end of the transmission line. Figures 1C, 1D, and 1E show these measurements and the resulting pulse widths of approximately 54.7ps, 54ps, and 51.6ps before the taper, after the taper, and at the end of the transmission line, respectively. Since there is very little change in the pulse width at the different points along the transmission line, we have hypothesized that the problem lies within the Auston switch. The next issue is the noisy signal, a problem that may also lie in the interlocking fingers of the Auston switch. As a result, further design optimization is needed to improve the Auston switch to make it more efficient in coupling the photocurrent pulse from the semiconductor onto the transmission line.

The final issue is that there are many reflections and reverse reflections. As shown in Figures 1C, 1D, and 1E, the measurements at each position on the transmission line were very similar, and there were no new reflections, meaning the transmission line taper and design was optimized for continuous pulse propagation. Given that there are no reflections at any positions along the line, the reflections causing the polarity changes in the pulse measurement can be assumed to originate from the impedances at the two ends of the line; we concluded that the detector tip end of the transmission line appears as a short, or closed circuit, and the Auston switch end appears as an open. Therefore, the detector tip appears to have almost zero impedance, causing it to send back a reverse or upside-down reflection when the pulse hits it. On the other hand, the Auston switch appears to have almost infinite impedance, causing it to send a reflection back with the same polarity when the pulse hits it. Based on the calculated phase velocity ($1.138x10^8$) of a wave propagating down the transmission line structure. The following image of the calculated position of the pulse along the transmission line as a function of time corresponds well with this analysis:



Since the propagation time from the end of the transmission line to Auston switch and back, 17.6ps, is less than the width of the measured pulses, themselves, we conclude that the measurements seen by the detector tip represent superpositions of shorter pulses.

V. Conclusion

Based on the measured and calculated results, we conclude that the tapered region and transmission line overall structure is well optimized for pulse propagation down the line, with minimal pulse broadening, no reflections from the tapered nanoscale region of the line, and minimal attenuation of the pulse amplitude. Future work will be devoted to optimizing the Auston switch and achieving the ideal 3-4ps pulse width for electrical switching of the nanodot load.

VI. References

[1] Y. Yang, R. B. Wilson, J. Gorchon, C. H. Lambert, S. Salahuddin, and J. Bokor, “Ultrafast magnetization reversal by picosecond electrical pulses,” *Sci. Adv.*, vol. 3, no. 11, pp. 1–7, 2017.

[2] F. W. Smith, H. Q. Le, V. Diadiuk, M. A. Hollis, A. R. Calawa, S. Gupta, M. Frankel, D. R. Dykaar, G. A. Mourou, and T. Y. Hsiang, “Picosecond GaAs-based photoconductive optoelectronic detectors,” *Appl. Phys. Lett.*, vol. 54, no. 10, pp. 890–892, 1989.

[3] D. H. Auston, “Picosecond optoelectronic switching and gating in silicon,” *Appl. Phys. Lett.*, vol. 26, no. 3, pp. 101–103, 1975.