Monolithic Nonlinear Transmission Line

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[ABSTRACT]

Superlattice Schottky Quantum Barrier varactors have been employed as nonlinear elements in nonlinear transmission line circuits. Short pulses with <37ps fall time have been detected in initial proof-of-principle experiments in good agreement with theoretical predictions leading confidence in the predictions of <20ps fall time for the next generation of NLTLs. The HP HFSS EM and MDS simulation codes have been employed to optimize the circuit layout and to provide an accurate device level equivalent circuit model. The resultant accurate EM model is utilized for transmission line equivalent circuit simulations.

This work is supported by the Department of Energy under contract DE-FG03-95ER94295, the Joint Services and Electronics Program under contract F4962092-C-0055 and the Lawrence Livermore National Laboratory LDRD program under contract LLNL-W-740J-ENG-48.

[INTRODUCTION]

A nonlinear transmission line (NLTL) is comprised of a transmission line loaded with varactors, where the nonlinearity arises from the variable depletion layer width which depends both on the DC bias voltage and on the AC voltage of the propagating wave. Monolithic NLTLs have been made by several groups utilizing coplanar wave guide and GaAs Schottky diodes for short pulse generation [1,2]. The output power and pulse duration are limited by the device breakdown voltage and the diode cut-off frequency. Ultrashort pulses have been obtained by compromising peak pulse voltages. Pulses with higher peak voltages were generated albeit with longer pulse duration. The trade-off between breakdown voltage and the cut-off frequency of Schottky diodes makes it difficult to simultaneously achieve high output voltage and ultrashort pulse width. In the present work, Superlattice Schottky Quantum Barrier (SSQBV) Varactors (SSQBV) are employed as nonlinear elements[3-5]. The MBE wafer doping profile of the SSQBV varactors is illustrated in Fig. 1, where superlattice barriers have been utilized to reduce the leakage current associated with standard quantum barriers. With modern MBE technology, devices are stacked vertically to provide high power handling capability. The cut-off frequencies of these devices are predicted to exceed 2THz. By using a back-to-back layout configuration, the SSQBV varactors have symmetric C-V curves, and therefore can be utilized to generate pulses with both polarities.

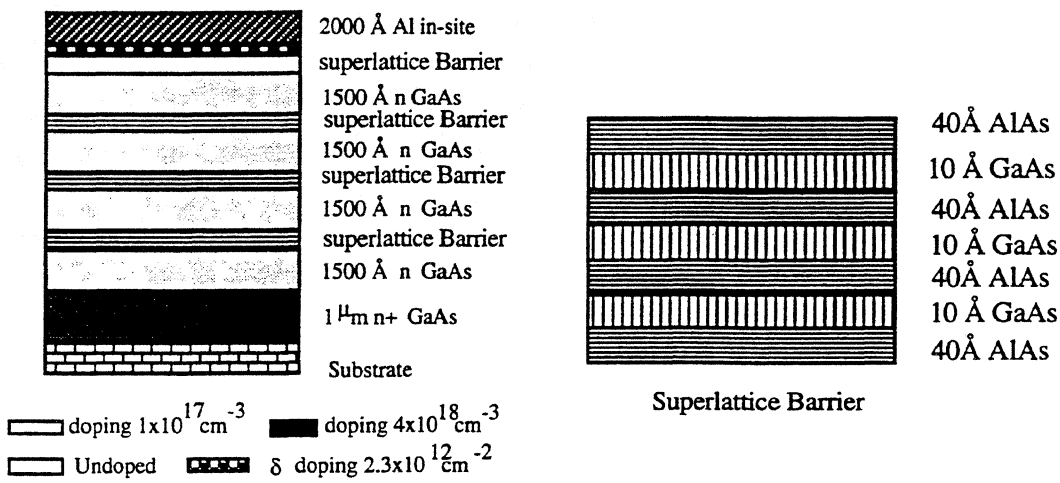


Fig. 1 GaAs SSQBV Wafer Doping Profile

[EM SIMULATION]

The HP high frequency structure simulator (HFSS) electromagnetic code has been utilized to optimize the diode layout and to reduce parasitic capacitance as well as series resistance. In the modelling, a back-to-back diode resides inside a waveguide and on top of the GaAs substrate. With properly defined electric and magnetic walls, the waveguide supports the TEM mode. As shown in Fig. 2, an embedded resistive layer under the metal fingers is utilized to simulate the n+ region.

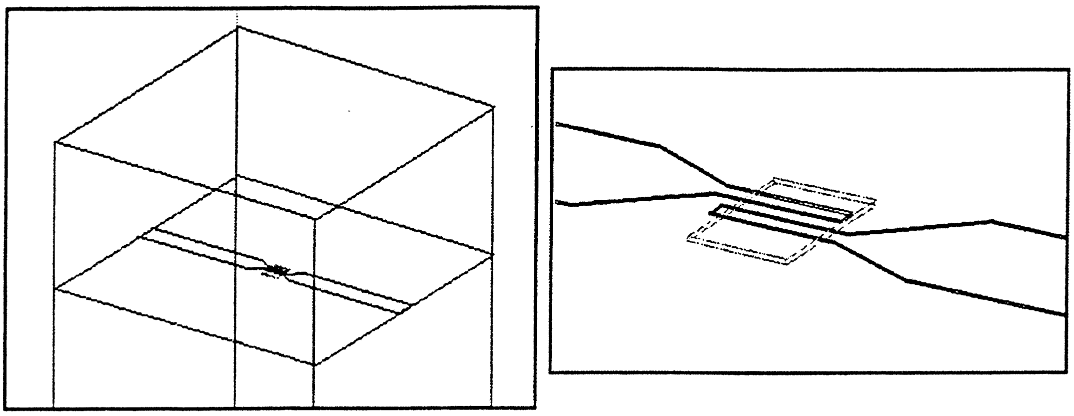
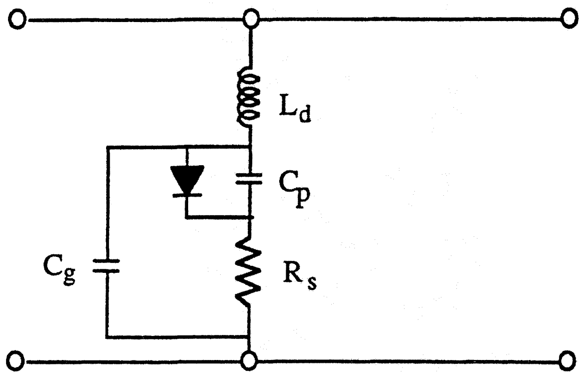


Fig. 2 The 3-D model for the HP HFSS Code

Frequency	S_{11}	S_{12}/S_{21}	S_{22}
30.4 GHz	0.647 −178.79	0.761 —111.87	0.642 −137.19
31.4 GHz	0.659 −178.91	0.751 —116.64	0.654 −127.46
32.4 GHz	0.673 −178.99	0.738 —121.62	0.667 −117.33

Table 1. S Parameters from HFSS Simulation

Table 1 shows the S parameters obtained from the HFSS simulations. Using these S parameters, an accurate EM equivalent circuit model has been generated by utilizing the HP MDS simulation tool. The equivalent circuit model is shown in Fig. 3. For a typical diode with 4μm x 20 μm finger dimensions and 4μm finger spacing, the series resistance from the n+ layer is 1.5 Ω while C_{min} is 14.1 fF which corresponds to 4.5 fF parasitic capacitance. These simulation results are consistent with our previous experimental results.



L_d=0.87 nH

C_p =14.14fF

C_g =0.11 fF

R_s = 1.5

Fig. 3. Simulation Model Utilized by the HP HFSS EM Code

[EXPERIMENTAL RESULTS]

Monolithic NLTLs have been fabricated on SSQBV wafers grown by Quantum Epitaxial Designs. DC characteristic measurements have been performed with a HP4140B pA meter (I-V) and a HP4279CV meter. With this three superlattice barrier structure, the breakdown voltage is 17.5V, and C_{max}/C_{min} is ~3.9.

An initial test system has been configured, as shown in Fig. 4, which includes Cascade WPH-405 Microwave Probes (DC-65GHz), an Avtech impulse generator (350 ps FWHM pulses) and a Tektronix 11802A digital sampling oscilloscope equipped with a 50GHz plug-in. A portion of the pulse signal from the Avtech pulse generator is utilized as a trigger signal for the sampling scope.

A hybrid NLTL is employed to precompress the input pulse, which has been fabricated utilizing MA46580-992 GaAs beam-lead varactor diodes. The output signal from the hybrid NLTL is a shock wave with ~100 ps fall time. The first proof-of-principle SSQBV based NLTL was only designed to generate pulses with ~26ps fall time and 15.0 V peak voltage, so that they could be accurately measured by our current test system. This transmission line is not designed for the highest performance (ultrashort pulse) but for the purpose of providing an accurate model.

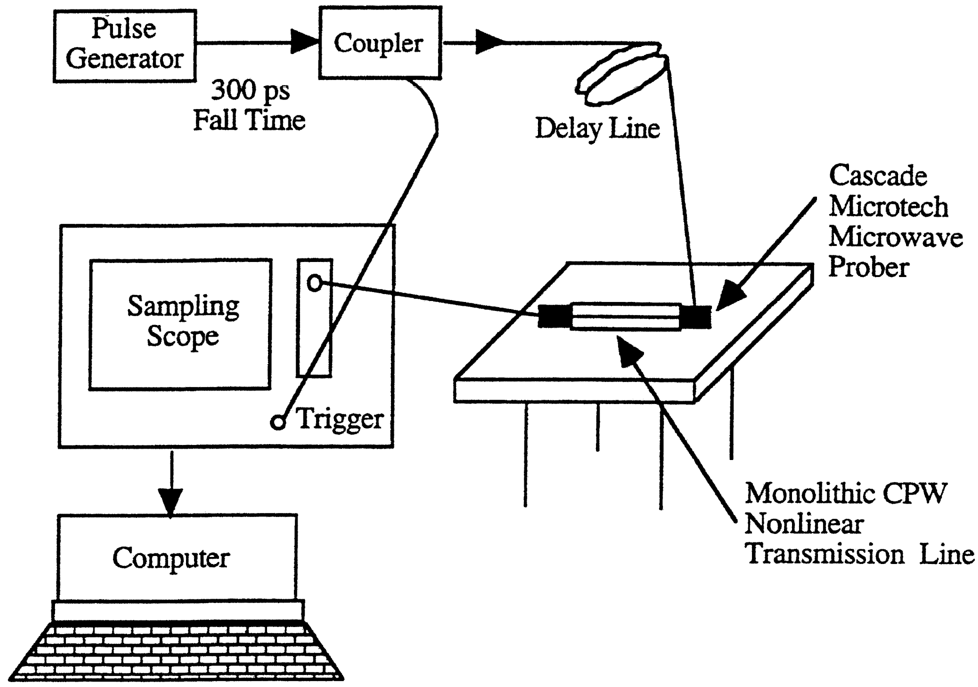


Fig. 4. Transmission Line Test Set-up

Both experimental and simulation (employing actual device and circuit parameters) results are shown in Fig. 5. Pulses with peak-to-peak voltage levels of 11.2 V and <37ps fall time were measured. It should be noted that a second pulse is also formed (albeit not separated from the first one), which indicates that this NLTL is not sufficiently long to fully compress the pulses.

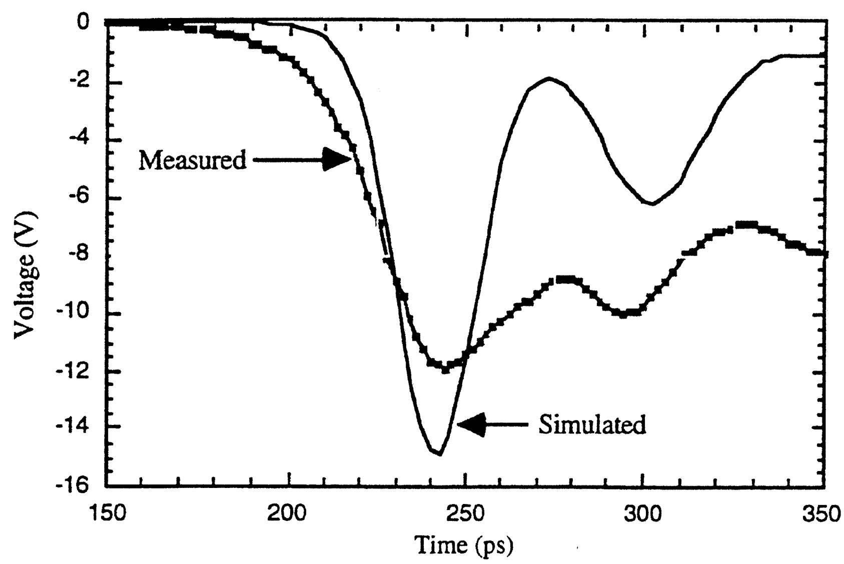


Fig.5. Comparison of Experimental and Simulation Results

[DISCUSSION]

Two new transmission lines have been designed and fabricated to generate >15V with ~20ps and ~10ps fall times, respectively. These two lines are currently under test. New wafer profiles have been designed to increase the power handling capability of quantum barrier devices by vertically stacking more then six barriers together. Lateral stacking techniques can be utilized to further increase the breakdown voltage, and varactors with >50 V breakdown voltages and >300GHz cut-off frequencies appear to be readily achievable.

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