Monolithic Nonlinear Transmission Line Using Multi-barrier Devices

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[ABSTRACT]

Schottky Quantum Barrier Varactors are employed as nonlinear elements in monolithic nonlinear transmission line (NLTL) applications. The epitaxial stacking structure together with the zero built-in voltage of the quantum barrier results in this device having a higher cut-off frequency and an enhanced breakdown voltage as compared to Schottky varactors. To reduce the leakage current associated with the quantum barrier, an AlAs/GaAs superlattice barrier is utilizied instead of an $Al_xGa_{1-x}As$ quantum barrier. Two monolithic NLTLs have been designed and fabricated. Hybrid NLTLs have been employed to pre-compress the input pulses.

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[INTRODUCTION]

Monolithic Nonlinear Transmission Lines have been made by several groups utilizing coplanar wave guide and GaAs Schottky diodes. Pulses with ~0.8 ps rise time and V_{pp} ~ 3 V have been obtained at 77K, and ~1.4 ps rise time with V_{pp} ~6V and ~4.5ps rise time with $V_{pp\sim}$ 12.6 V has been obtained at room temperature [1-4]. The output power and pulse width are limited by the breakdown voltage and the diode cut-off frequency. The trade-off between the breakdown voltage and the cut-off frequency of Schottky diodes makes it difficult to simultaneously achieve high voltage (Vpp>15 V) and ultrashort pulsewidth (<3 ps). With modern MBE technology, however, it is possible to vertically stack several devices in series and to obtain much higher power handling ability. Two such structures, Multi-Quantum Barrier Varactor (MQBV) and Schottky Quantum Barrier Varactor (SQBV), were conceived by our group which have proven to have higher cut-off frequency and increased power hadling ability as compared to conventional Schottky diodes in frequency multiplier applications[5]. The MQBV is a stacked quantum barrier varactor, as shown in Fig. 1. The zero built-in voltage of the quantum barrier and the epitaxial stacking structure results in the MQBV having a high cut-off frequency and high breakdown voltage. The SQBV is comprised of a Schottky barrier on top of an MQBV structure, as shown in Fig. 2. A δ doping layer is added to increase the nonlinearity of the SQBV. With a Schottky contact instead of an ohmic contact, the SQBV has a higher diode cut-off frequency but reduced nonlinearity compared to the MQBV. By using a back-to-back layout configuration, the MQBV and SQBV varactors have symmetric C-V curves; hence, these devices have strong nonlinearities for both positive and negative voltages. The cut-off frequency of these devices is predicted to exceed 2 THz. Using MQBV and SQBV structures, V_{pp}> 20 V and 1-3 picosecond pulses appear to be readily achievable. In this work, the SQBV structure is utilized. To reduce the leakage current associated with quantum barriers, we also employed superlattice barriers instead of quantum barriers[6], as shown in Fig.3.

[DESIGN AND DISCUSSIONS]

A monolithic nonlinear transmission line is a coplanar transmission line loaded with varactors as nonlinear elements. The nonlinearity of the transmission line arises from the variable depletion layer width which depends on the DC bias voltage and on the AC voltage of the propagating wave. The voltage dependency of diodes causes the wavefornt steepening, and periodic loaded transmission line has strong dispersion near the Bragg cut-off frequency. The balance between these two factors causes the formation of short pulses. Each NLTL is comprised of many sections. An equivalent circuit of our NLTL is shown in Fig. 4, which serves as the basis of our designs and simulation. The coplanar transmission lines are modeled as an RLC ladder network, where L and C_{line} are, respectively, the inductance and capacitance per section, and R represents the skin loss. The SQBV is modeled as an MQBV (C_2) in series with a pair of back-to-back barrier-N-N+ (BNN) varactors (C_1, C_3). Here R_s is the series resistance, while R_1, R_2, and R_3 stand for the leakage current over the barriers. To match external circuits, the input and output impedences are traditionally chosen as 50Ω, so are the large signal impedances of our NLTLs. To reach a high nonlinearity, high impedance coplanar transmission lines are prefered. Also, to emphasize the nonlinearity of the NLTL, wafer profiles are designed to have a large C_{max}/C_{min} ratio.

Two monolithic nonlinear transmission lines have been designed to generate waveforms with 10ps and 20ps fall time. The transmission line impedance is chosen as 85Ω, the diode areas are 144 μm^2, and 288 μm^2, and the section lengths are 200 μm and 400 μm.

[PRELIMINARY TEST RESULTS]

Monolithic NLTLs have been fabricated on SQBV and SSQBV wafers with a three mask process. Both wafers were grown by Quantum Epitaxial Designs. DC characteristic measurements have been performed with a HP4140B pA meter (I-V) and a HP4279 CV meter. As shown in Fig. 5, both devices have similiar C-V curves. For SQBV device, the C_{max}/C_{min} ratio is 3.8, while for SSQBV, the ratio is 3.9. The I-V curves of SQBV and SSQBV devices are shown in Fig. 6. The breakdown voltages for both devices are >17V. At low voltage levels(<15V), the SSQBV has less leakage current, and at higher voltages (>15V), the SQBV has less leakage current.

A initial test system has been setup, 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 50 GHz plug-in, as shown in Fig. 7. A hybrid nonlinear transmission line has been fabricated utilizing MA46580-992 GaAs beam-lead varactor diodes. The hybrid NLTL is employed to pre-compress the input pulses. The output of the hybrid NLTL is a shock wave with fall time 60-90ps and Vmin ~ -22V. The monolithic lines are current under test.

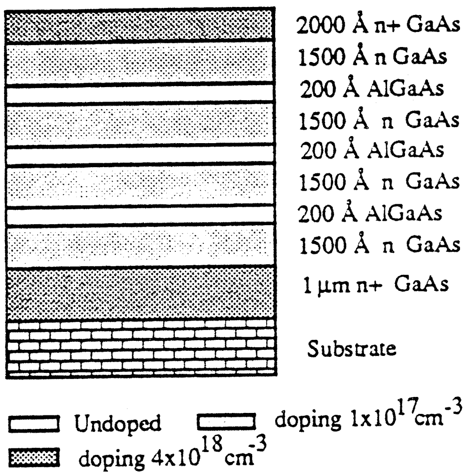

Fig.1 GaAs MQBV Doping Profile

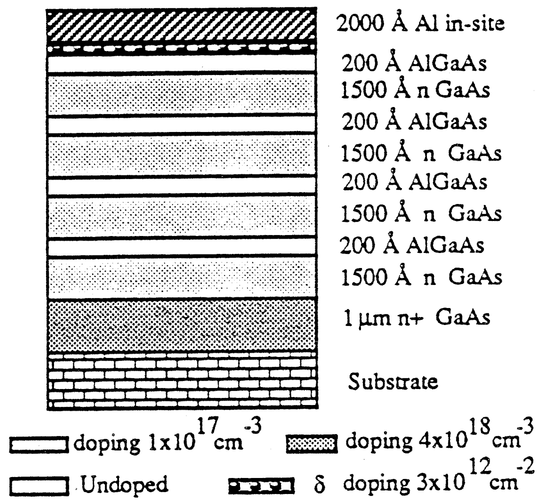

Fig.2 GaAs SQBV Doping Profile

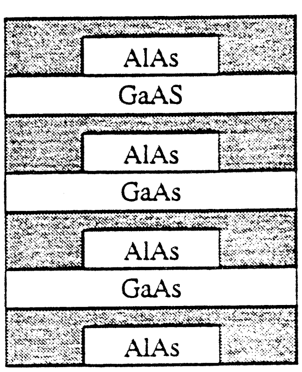

Fig.3 Superlattice Structure

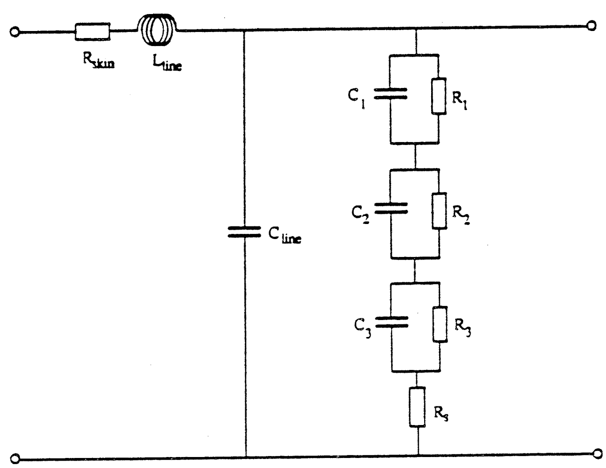

Fig. 4 Equivalent Circuit of One Section of an NLTL

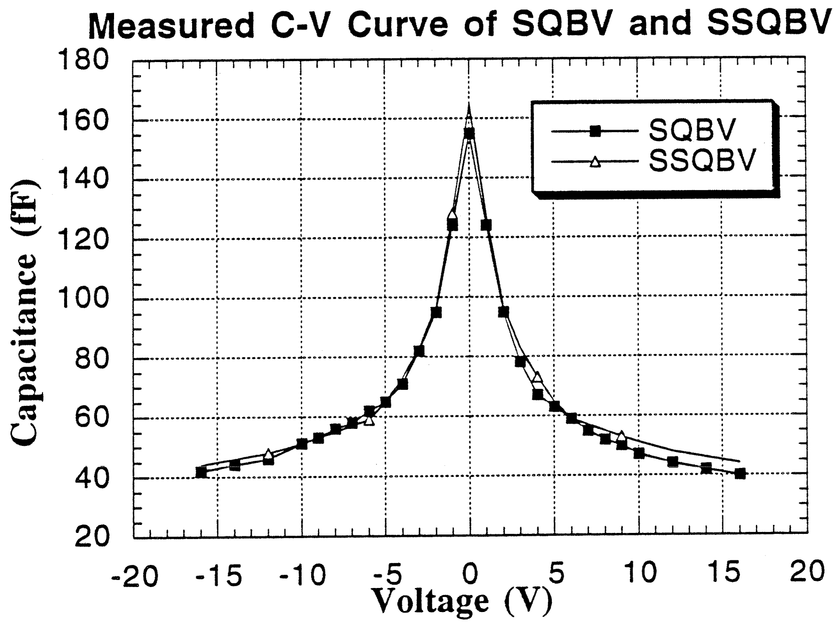

Fig. 5 Measured C-V Curves

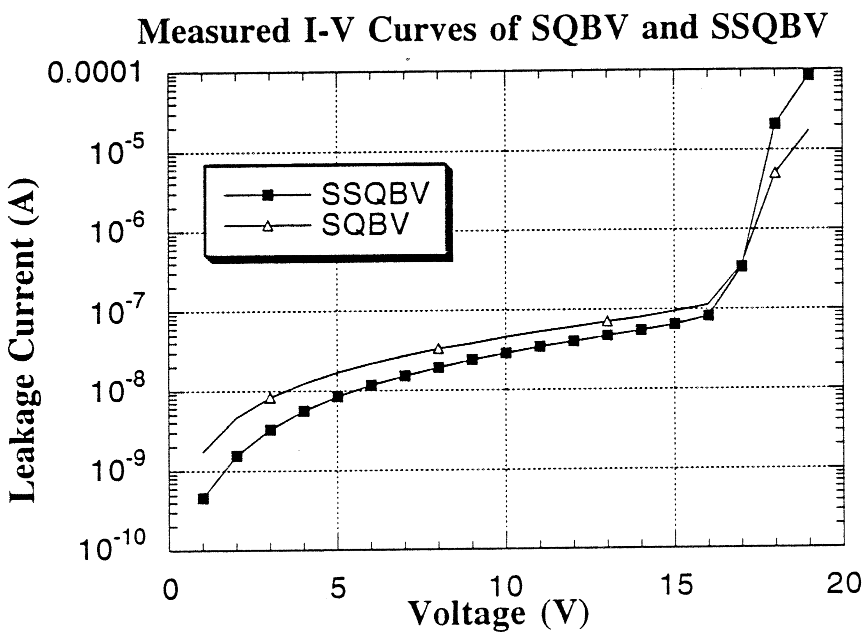

Fig. 6 Measured I-V Curves

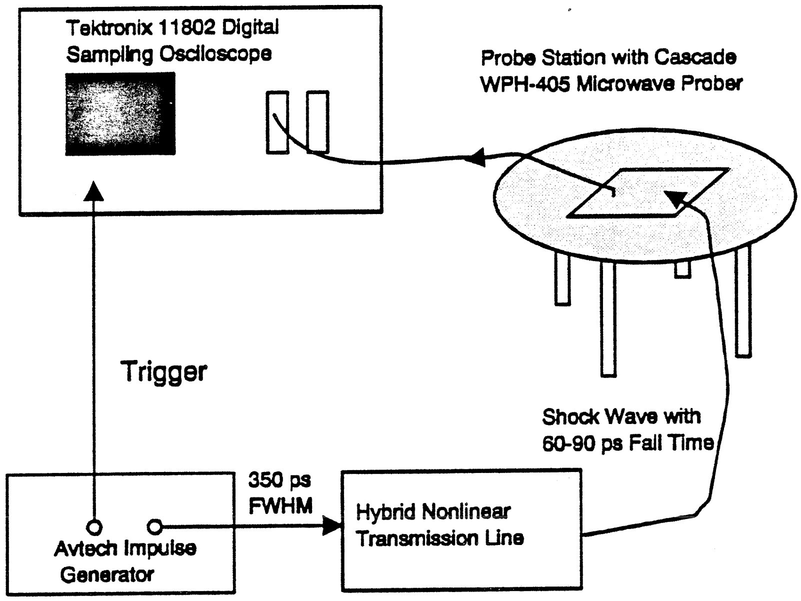

Fig. 7 Initial Test Setup

[REFERENCES]

[1] M. Rodwell, M. Kamegewa, Ruai Yu, M. Case, E. Carman, K. Giboney, *IEEE Trans. on Microwave Theory and Techniques*, Vol. 39, 1194, (1991).

[2] D. W. Van Der Weide, J. S. Bostak, B. A. Auld, and D. M. Bloom, *the 17th International Conference on Infrared and Millimeter Waves, Pasadena*, 97, (1992)

[3] E. Carman, M. Case, M. Kamegawa, R. Yu, K. Giboney and M. Rodwell, *IEEE Trans. on Microwave Theory and Techniques*, Vol. 40, 819, (1992)

[4] C. Raman, J. P. Sun, W. L. Chen, G. Munns, J. East, G. Haddad, *Third International Symposium on Space Terahertz Technology*, 146 (1992)

[5] H-X. Liu, L. B. Sjogren, N. C. Luhmann, Jr., D. B. Rutledge, *International Jounal of Infrared and Millimeter Waves*, Vol. 13, 251, (1992)

[6] W-M. Zhang, H. Shi, C.W. Domier, N.C. Luhmann, Jr., *the 17th International Conference on Infaraed and Millimeter Waves, Pasadena*, 408 (1992).