11th International Workshop on Computational Electronics
TU Wien, 25-27 May 2006

Computer Simulation Experiment on Prospects of ZnS as Novel Material for High mm-Wave Power /Low Noise Generation in Impatt Mode

S. P. Pati and P. R. Tripathy
Department of Physics, Sambalpur University, Jyoti Vihar-768 019, Sambalpur, Orissa
Email: patispsu@sancharnet.in

Impatt Devices have been identified as premier class of Solid State Electronics Device for stable rf power generation used for present day e-communication systems with the added advantage that any form of p-n junction fabricated from any semiconductor material, can exhibit Impatt action based on combined physical phenomena of transit time delay and avalanche phase delay. Studies on new materials are being carried out by several groups spreading over the globe to enhance the rf power/efficiency and reduce the avalanche noise in this class of devices even at far mm-wave frequencies. Recent report [1] presents ionization rate and other material parameters in ZnS which is also high band gap semiconductor. The reported high ionization rate at high field with nose dive fall with lowering of electric field provided intuition for ZnS becoming a novel material for Impatt devices. The authors carried out computer simulation experiment to compute microwave characteristics of ZnS Impatt through use of a sophisticated three phase computer algorithm.

At the outset, the extracting the values of electron ionization rate (α) at different electric field values, an usual exponential as well as high order polynomial form of equations for α~E, are framed and used following curve fitting technique ensuring the correspondence to reported plot. Double Iterative Computer method incorporating drift, diffusion and tunnel currents, for DC analysis solving Poison, Carrier Continuity and Space Charge equations simultaneously, is framed to compute breakdown electric field/voltage (Em/Vb), normalized avalanche zone (x_a/W), qualitative value of efficiency (η) etc. from the final solution. In the second phase of analysis, another double iterative computer method is framed for high frequency analysis of ZnS Impatts solving simultaneous integrated second order device equations on diode resistance (R) and susceptance (X) subject to fulfillment of usual boundary conditions to compute rf properties of diode like BW showing exhibition of (-) rf negative conductance (G), the values of negative resistance (r), r(x) profile, avalanche phase delay (θa) etc. The third complicated iterative computer software is developed to solve second order integrated equations on noise complex field for determination of avalanche noise and noise measure considering noise element progressively at individual space step and then integrating over space for particular noise element separately and then for all noise elements. All the computer programs are designed for quick convergence towards satisfying the usual boundary conditions.

The ZnS p-n junctions are then designed for various frequencies of operation specially for atmospheric window frequencies (12 and 35 GHz) and optimized for current density, diode doping/width, punch through factor to ensure the lowest avalanche zone, closest location of Em to junction plane and θa≅ 90 degree. The optimized diodes have been analyzed through use of the three phase computer method and DC; microwave and noise characteristics have been computed and presented in table 1 and figures 1 & 2. The results indicated some favourable features for ZnS Impatts.

The material has very high band gap energy of 3.68 eV. Thus as seen from the table, the ZnS junction would provide very high break down voltage, 661 V for X-band as against 105 V for corresponding Silicon Impatt. The nose dive fall of ionization rate below $1.6\text{x}10^8$ V/m, causes very thin avalanche zone (xa/W=8% as against 45% for Si). This factor would enable the ZnS Impatt diode to give an efficiency of 28.5 % as against 13 % for Si. It may be mentioned that the theoretical optimum efficiency based on 50% rf modulation is only around 30%. Thus it may be possible to achieve the theoretical optimum efficiency for ZnS. The Frequency-negative conductance plots for 12 and 35 GHz optimum frequencies are shown in figure 1. Further the negative conductance and resistance values for ZnS X-band devices are higher by nearly two times compared to Silicon Impatt. Figure 2 shows the mean square noise voltage at different frequencies. The most important result that can be seen from table and figure 2 is that the ms noise voltage associated in ZnS Impatt diode is $1.87\text{x}10^{-17}$ V^2.s at 12 GHz as against 70.6 $\text{x}10^{-17}$ V^2.s for 12 GHz Si diode. For 35 GHz similar results could also

ISBN 3-901578-16-1

be noticed.

The high value of Vb would provide high input power and the efficiency being high, ZnS diode is expected to give high rf power. The high value of negative conductance and resistance would help to increase rf power further. The avalanche noise which is an evil factor of Impatt diode in general would be only 3% for ZnS X-band diodes compared to corresponding Silicon diode. Thus possible high power generation at high efficiency and low noise may make ZnS a s a novel material for m/mm-wave generation

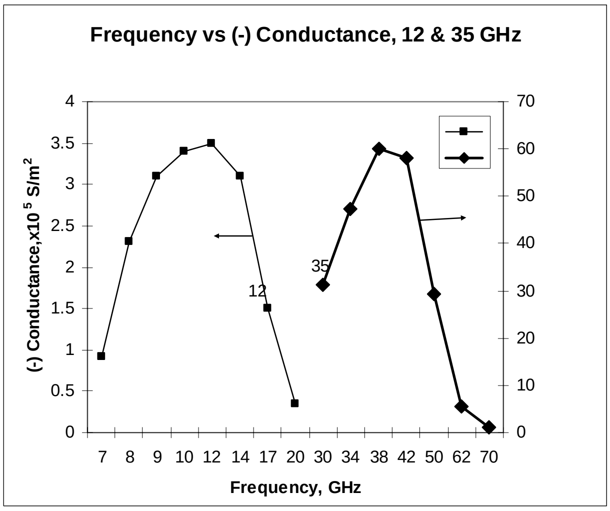

Fig. 1. Frequency-(-) Conductance plots for ZnS Impatt Diodes

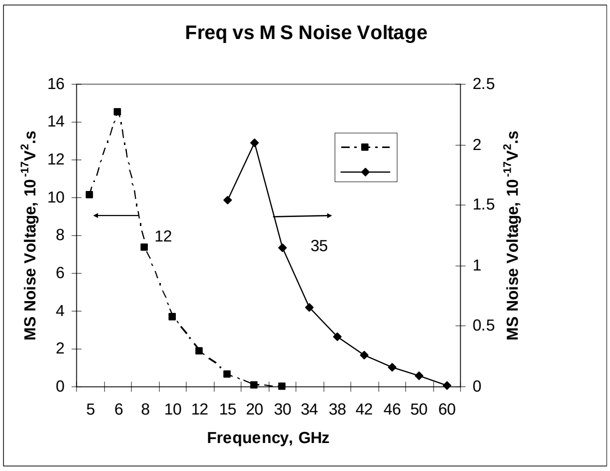

Fig. 2. Frequency-Mean Square Voltage for ZnS Impatt diodes

	ZnS		Si	
	12GHz	35GHz	12 GHz	35 GHz
Em, 10^7 V/m	17.95	18.52	3.65	4.77
Vb, V	661	301	105	41.1
Xa/W, %	8.12	12.1	45.8	47.1
η, %	28.1	26.0	13.0	12.1
-G, x10^5 S/m^2	3.47	60	2.6	32.0
-R, x10^{-6} Ω.m^2	7.01	5.16	0.209	0.0275
<V2>/df, at fp 10^{-17} V^2.s	1.87	0.413	70.6	3.99

Fig. 3. Some properties of ZnS and Silicon IMPATT Diodes at 12 & 35 GHz.

.