MBE Regrowth of LEDs on VLSI GaAs MESFETs[†]

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We demonstrate for the first time the regrowth and monolithic integration of heterostructure LEDs on fully processed VLSI GaAs MESFETs. Commercially available, self-aligned VLSI GaAs MESFETs, with tungsten-based refractory-metal Schottky gates, nickel-based refractory-metal ohmic contacts, and aluminum interconnection metallization, have been shown to be stable after 3 hours at 525°C ± 10°C[4,5]. Thus, it is now possible to regrow optical sources on fully processed MESFET circuitry with lowered-temperature molecular beam epitaxy (MBE). This allows one to build high density, complex electronic circuitry with optical inputs and optical outputs. Such optoelectronic circuits are useful for high speed optical communications, optical computing, or smart pixels.

Our specific circuit application is for optoelectronic neuron arrays in optical neural networks. Each neuron circuit has two photodetectors to receive the optical inputs, electronic circuits to perform a nonlinear thresholding function on the photocurrent and a LED to transmit the output of the neuron. A typical optical neural network has neuron densities of 1×10^4 neurons/cm^2. This puts stringent requirements on the power dissipation and uniformity of the circuit, but these requirements can be met with an industrial fabrication process[6].

Each branch of the circuit accepts two optical inputs, I_1 and I_2. If I_1 equals I_2 then the gate voltages of both MESFETs are $V_d/2$ which turns both transistors off. The current sinking transistor draws its current entirely from the LED. If I_1 or I_2 are not equal, then the gate voltage on one of the two MESFETs will be high (V_d) turning the transistor on and thus shorting the LED. Therefore the LED is only turned on when $I_1 \approx I_2$. The photodetectors are enhancement mode MESFETs with the gate connected to the source. These optical FETs provide the nonlinear IV characteristics required.

The electronic circuit was designed and fabricated through MOSIS using Vitesse Semiconductor Corporation's HGaAs2 process. Half of the chip was left blank for the LED regrowth. The fabricated chip was electrically tested and then the dielectric stack covering the blank area was removed using HF. A superlattice was grown to impede the propagation of defects from the semi-insulating substrate. The LED structure consists of double heterostructure nAlGaAs/iGaAs/pAlGas layers. The total growth time was nearly 4 hours at the lowered growth temperature of 530°C. The polycrystalline GaAs that covers the portion of the chip where the circuits are, was removed by masking off the crystalline GaAs with photoresist and then etching with a phosphoric etchant. The LED was fabricated and connected to the circuit after the regrowth.

The circuits were tested electrically after the growth and their performance was compared to the original circuit. The DFET saturation voltage is the same, whereas the saturation current has decreased by approximately 10%, and the source-to-drain resistance has increased by 40%. The peak photoluminescence (PL) of the epitaxial material was 10% less than the PL of a control blank wafer that was grown at the same time. LEDs fabricated on the chip and the control wafer had comparable efficiencies and the desired nonlinear optoelectronic thresholding function has been achieved. Thus, we have demonstrated for the first time an extremely attractive regrowth technology for high density optoelectronic circuits which takes full advantage of commercial VLSI GaAs MESFETs.

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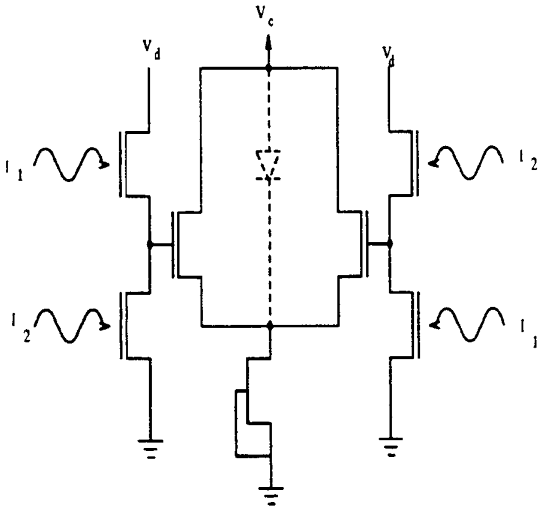
[4] K.V. Shenoy, C.G. Fonstad, Jr., et. al., LEOS '92 Conf. Proc. (Boston, MA), Nov. 16-19 1992, 594-595.

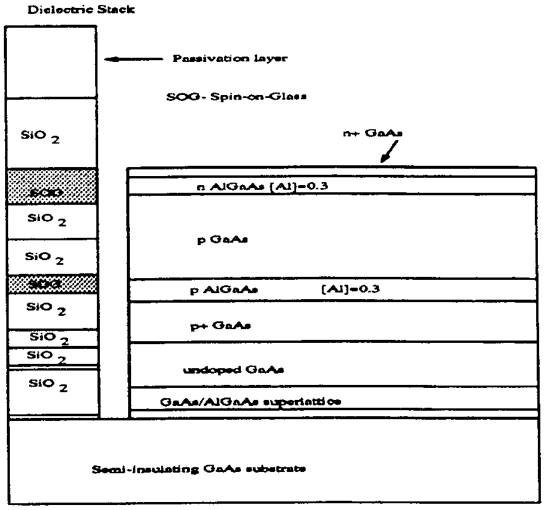
[5] K.V. Shenoy, C.G. Fonstad, Jr., and J.M. Mikkelson, submitted to IEEE Electron Device Letters, Dec. 1992.

[6] S. Lin, A. Grot, J. Luo, and D. Psaltis, to be published in Applied Optics 1993.

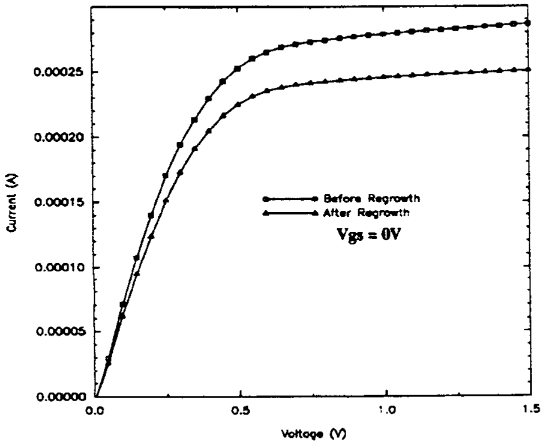
Optoelectronic Neuron Circuit



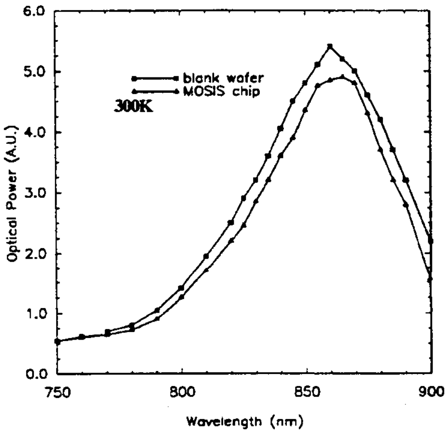
Regrowth Cross-Section



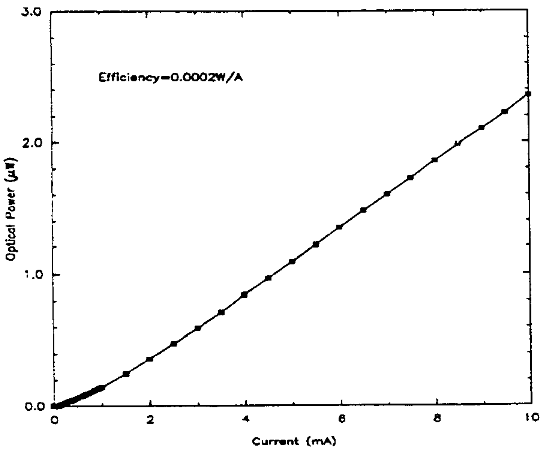
DFET Load I-V Curve



LED Photoluminescence



LED I-V Curve



LED-DFET Load I-V Curve