SI DIODE UNDER AVALANCHE BREAKDOWN AS A LIGHT EMITTING SOURCE FOR VLSI OPTICAL INTERCONNECT

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ABSTRACT

Light emission properties of a reverse biased silicon diode under avalanche breakdown are being investigated for optical inter-connections for VLSI systems. Silicon being an indirect band-gap semiconductor, is a poor material for light emission from forward biased diodes. The optical emission at reverse breakdown is weak but has been coupled to an optical fiber and detected by a photodiode, indicating its potential for VLSI interconnect.

INTRODUCTION

Optical inter-connections for VLSI systems require generation, routing, and detection of light at the level of integrated circuit chips and circuit boards. Photon emission from a reverse biased silicon diode under avalanche breakdown was first observed in the fifties but, due to its poor efficiency, was not pursued as a practical light source. Silicon technology is well established and will be present for the years to come; therefore it is worthwhile to study the light emitting properties of Si p-n junction diodes under reverse bias as a photon source for VLSI optical interconnect.

Silicon being an indirect bandgap semiconductor, is a poor material for light emission from forward biased diodes, though it is good for photo detectors over a large range of frequencies. A weak light emission at reverse breakdown due to its poor light output efficiency (≈ 10^-5 photons/electron) [1] does not qualify the device as a light source, in comparison to the III-V compound light emitting sources, for most of the optical systems. But the device seems to have a potential for VLSI optical interconnect due to the following reasons:

(a) For silicon integrated circuits the light source can be fabricated along with the rest of the components, on the same substrate.

(b) Experimental results indicate that though the light output power is small, it is sufficient for short interconnections.

THEORY

Visible electro-luminescence from a silicon p-n junctions under conditions of avalanche breakdown has been reported and explained previously [2 - 6]. The breakdown condition is generally regarded as being a solid state analog of a gas discharge plasma, the so called microplasma. At the microplasma regions the light originates in small discrete spots, of the order of 1μm or smaller [4], under the condition of high electrical field.

Essentially, in the microplasma or avalanche region itself, both hot holes and hot electrons are present up to the pair production threshold for holes (2.4 eV) and that for electrons (1.8 eV) due to high accelerating field. The phonon scattering plays an important role in the indirect bandgap energy transitions to assist in momentum conservation. This then makes the direct transition with Δk = 0 possible, radiating in the visible part of the spectrum, during
recombinations taking place in the avalanching region [7].

The time variation of luminescence which accompanies the avalanche breakdown process is governed by the lux-ampere characteristics deexcitation time given by [8]

\[ \tau_{\text{eff}} = \frac{\tau_6}{\tau + \tau_6} \]

where \( \tau_6 \) and \( \tau \) are the transit time of carriers across the multiplication layer and the total carrier life time in the barrier layer respectively. Usually, \( \tau_6 \ll \tau \) and therefore \( \tau_{\text{eff}} \approx \tau_6 \).

The characteristic deexcitation time governs the delay of the luminescence relative to the avalanche current. With an estimate of \( \tau_6 = 10^{-12} \) sec, this phenomenon has potential for practical applications as a nanosecond light source.

**EXPERIMENTAL RESULTS**

Many novel diode geometries of p-n junction for light emission have been designed and fabricated on silicon substrates. The starting substrate is boron doped p-type, with a resistivity of \( \approx 2 \) ohm-cm. After p+ diffusion, \( R = 13.5 \) ohm/\( \mu \) and the oxide layer thickness is \( \approx 7600 \) A. For n-diffusion liquid phosphorous spin-on technique is used. After this processing, \( R = 15 \) ohms/\( \mu \) and the oxide layer thickness is \( \approx 5000 \) A. For metal contacts Al deposition was made in E-beam evaporation system.

The design criteria for these structures are to optimize photon emission from the smallest junction area. Based on these requirements and processing constraints, the layout plans for some of the diode geometries developed are shown in Figure 1a. These diodes exhibit light emission with the application of reverse bias. Figure 1b shows an illuminated square spiral diode structure under avalanche breakdown. Illumination is observed to be highly localized at the junction edges.

The reverse I-V characteristic curve of one of the diodes fabricated are not smooth and suggests multiple possibilities including the presence of many micro-plasma regions in the diode junction.

Studies on the light emitting properties of these devices are being continued with the experimental

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**Figure 1.** Various diode geometries fabricated for testing.

**Figure 1(b).** Illumination from a square spiral diode structure.
set-up shown in Figure 2. The light output from the silicon diode is coupled to a pin photo diode through an optical fiber. The photo diode is followed by a very high gain (55 dB) two stage amplifier circuit shown in Figure 3.

Under DC reverse bias the photon emission from the Si diode starts at the onset of breakdown, about 9 volts. The light emission increases with increasing reverse biasing voltage in breakdown region. The output voltage of the optical receiver vs. the reverse biasing applied to the light emitting p-n diode is plotted in Figure 4.

With the application of a pulse waveform riding on a DC level of 7 volts, the receiver shows the rectangular wave response. With the designed detection circuit the rise time under pulsed operation is 18 µ sec; this limitation however has been shown to be a result of the circuit itself. The pulsed response is shown in figure 5.

ACKNOWLEDGEMENT

This work is supported by the DARPA Optoelectronics Program in the State of Florida and by Subcontract 87-210 with Auburn University.

REFERENCES


Figure 2. Experimental set-up to detect light emission from the Si diode.
Figure 3. Optical receiver circuit diagram.

Figure 4. 

Figure 5. Pulsed response $V_o$ (upper trace) to a input to the Si diode (lower trace).