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A Monolithically Integrated Photodetector-Amplifier Using a-Si:H p-i-n Photodiodes and Poly-Si Thin-Film Transistors

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Two-dimensional photodetector arrays with independent access to each pixel are crucial for various future optoelectronic systems such as free-space photonic switching systems and optical parallel-processing systems. To achieve such two-dimensional arrays with massive pixels, we propose a photodetecting circuit consisting of a bridge photodetector circuit and a CMOS differential amplifier, both monolithically integrated on a transparent substrate. In this work, we have fabricated and characterized a test circuit using a-Si:H p-i-n photodiodes (PDs) and poly-Si thin-film transistors (TFTs) to demonstrate the feasibility of such photodetector-amplifier.

Two a-Si:H p-i-n PDs of the same device area are used in the circuit. One of them is shielded from the input light to generate only a dark current. These two PDs and poly-Si TFTs make a bridge circuit. The output of the bridge circuit is the input to a CMOS differential amplifier consisting of n- and p-channel poly-Si TFTs. Thus the effect of the dark current and the non-uniformity can be canceled and an amplified output voltage is obtained. The bias current, J_{BIAS}, in the amplifier is controlled independently.

The test circuit was built on a quartz substrate. N- and p-channel poly-Si TFTs with minimum channel length of 10 μm were fabricated using a recrystallized LPCVD poly-Si film. The a-Si:H p-i-n PDs were fabricated using the plasma-enhanced CVD method. For one of the PDs, a 100-nm thick Mo film was patterned on the transparent electrode to shield the input light. The mobilities of the poly-Si TFTs were 88 cm^2/Vs for n-channel and 65 cm^2/Vs for p-channel. The responsivity of the a-Si:H p-i-n PD was 0.17 A/W at a bias voltage of 0 V at the wavelength of 633 nm which was used in this work.

The effect of the differential amplifier is very noticeable. The bridge circuit output, which is around 1 V or less for input light intensities from 4 to 400 $\mu W/cm^2$, is amplified to voltages close to V_{DD} (15 V in this case). It was confirmed that V_{OUT} (output voltage) vs. I_{IN} (input light intensity) characteristics can be controlled by changing J_{BIAS}. When J_{BIAS} is kept relatively small (on the order of 10^{-11} A), the circuit works digitally with V_{OUT} close to either 0 V or V_{DD} depending on I_{IN}. When J_{BIAS} is of the order of 10^{-8} A, V_{OUT} shows gradual increase with increasing I_{IN}. This indicates the possibility of using the circuit as an analog photodetector-amplifier as well. The power consumption of the circuit depends only slightly on I_{IN}. The power consumption of the circuit is 60 μW when J_{BIAS} is less than 10^{-10} A and I_{IN} is 400 $\mu W/cm^2$. This is low enough to use the circuit in a two-dimensional array of 10^3 pixels or greater.

In conclusion, we have proposed and demonstrated the feasibility of a photodetecting circuit with an integrated amplifier. With an integrated photodetector-amplifier, it becomes possible to overcome the pixel number limit in conventional photodetector arrays which is determined by the dark current of PDs and the leakage current of the TFTs that pick up the photocurrent. Possible applications include signal monitoring in free-space optical switching and optical information processing using "smart pixels" in which optical signal is detected and processed electrically in each pixel.

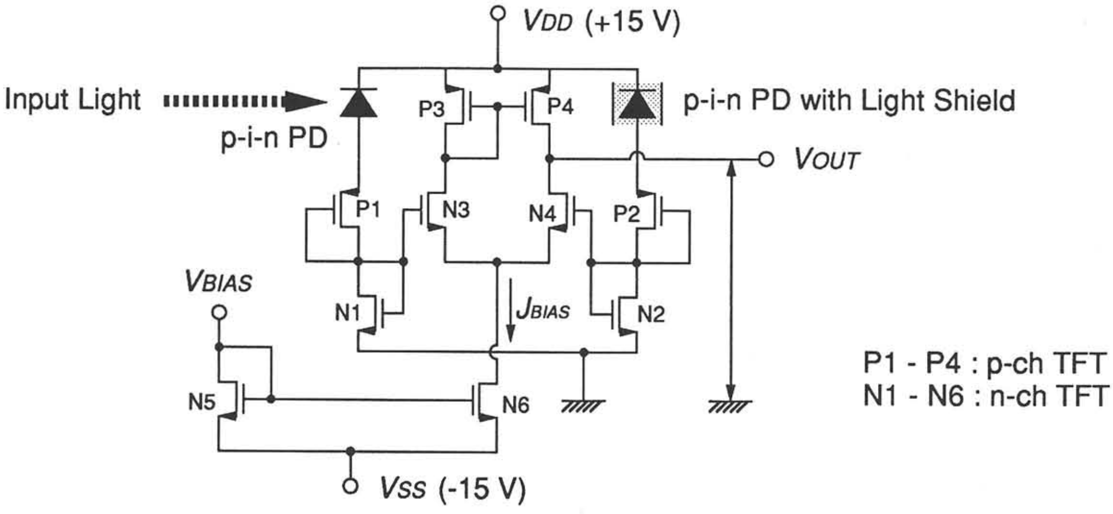

Fig. 1. Circuit diagram of the photodetector-amplifier.

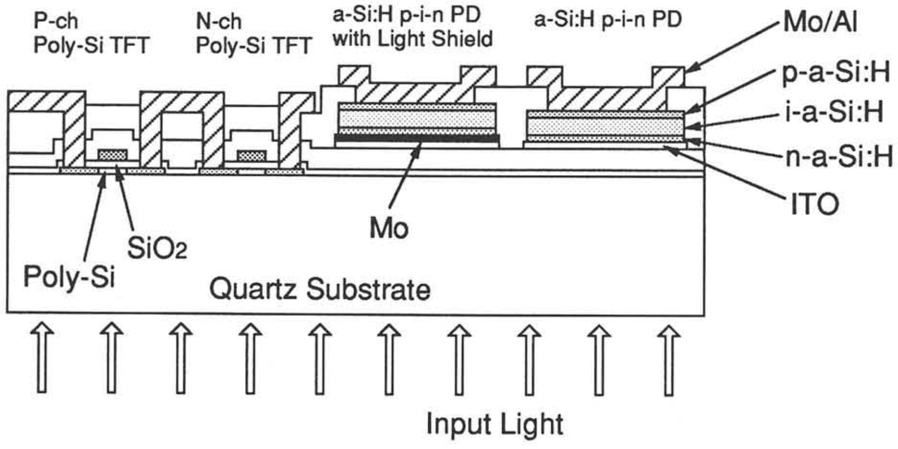

Fig.2. Schematic cross-section of the photodetector-amplifier.

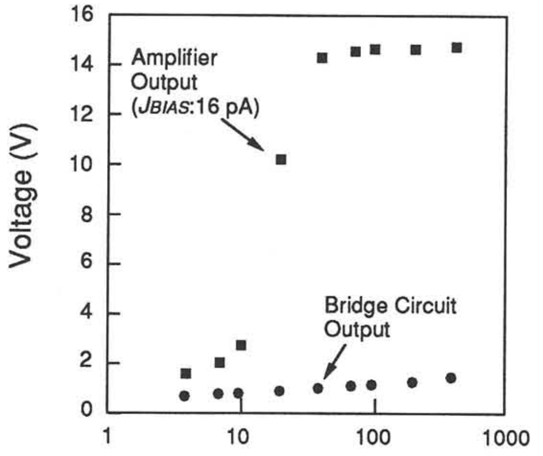

Fig. 3. Bridge output voltage and amplifier output voltage as a function of input light intensity.

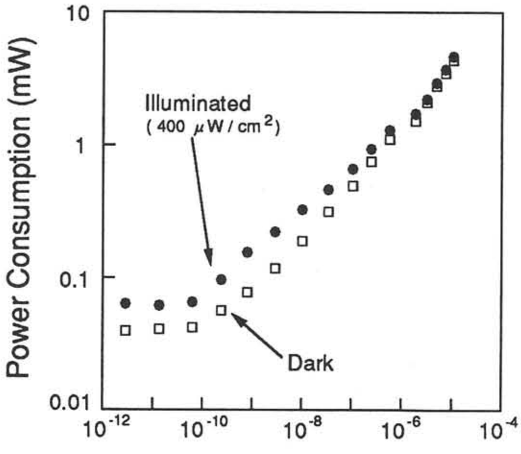

Fig. 4. Relation between power consumption of the circuit and bias current.