Image Kernel Implementation by Spatial Arrangement of Multiple Quantum Well Diodes

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Abstract. We report the operation of the image processor based on spatial arrangement of quantum well diodes at reduced incident power and bias voltage. Linear relation between the optimum electrical biasing for a given incident power of an electro-absorptive modulator is presented that is used to convert the electrical filtered image to optical one.

Keywords: Quantum-well devices, Analog image processing, Integrated optoelectronic circuit.
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INTRODUCTION

Optical image processing through the spatial arrangement of photodiodes is well known in literature mainly to detect the edges [1-4]. Figure 1 shows the schematic operation for a pixel of image. The cross-convolution is performed using a moving window of weights known as kernel with typical dimension as 3×3. Each pixel is processed by centering the window on the pixel and computing the weighted sum of intensity of neighboring pixels. This process is carried out by optoelectronic image convolution with a point spread function of a filter. The filtered image is reproduced by using electroabsorptive modulator (EAM) that is controlled by the net current of optoelectronic convolver. The structure is based on the quantum well self-electrooptic effect technology. So far, the operation of several types of kernels was evaluated [3-4], linear operation is proved and optimum operating point was determined at 175 nW of incident power beams and reverse bias voltage of 8-10 V [2]. We observed a linear relation between the optimum electrical and optical biases such that with lower power of carrier beam than 175 nW, the optimum bias voltage is reduced. Here, we describe this phenomenon, optimize the operating point at low intensity of incident carrier, and explain the phenomenon through the exciton generation.

EXPERIMENT

In the optoelectronic circuit shown in Fig. 1-c the power of incident beams was adjusted at 51 nW. As illustrated in Fig. 2, the maximum index of modulation was obtained at a voltage lower than 4.7 V with one order of magnitude reduction in comparison with Fig. 4 in Ref. 2. There the optimum voltage was in 8-10 V range for 175 nW of incident beams. Also, the dynamic range is reduced to about 65 nW. Higher bias voltage than 4.7 V beside of not able to enhance the linearity range and modulation index, can lead to change of mode of operation to bistable, indicated by a dip after knee in Fig. 2. In this case, the exciton resonance shifts to longer wavelengths than 850 nm such that the exciton strength and the optical absorption are reduced.

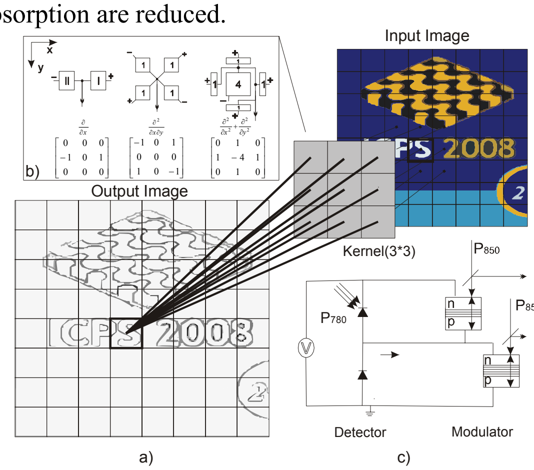

FIGURE 1. a) Schematic optical image processor using a 3×3 kernel matrix. The detection of borders is exaggerated respect to selected resolution only for clarity. b) Typical 3×3 kernel matrix and corresponding implemented kernels by spatial arrangement of reverse biased photodiodes. The relative area of reverse biased photodiodes is shown by numbers. c) Configuration for 1^{o}-order image differentiator.

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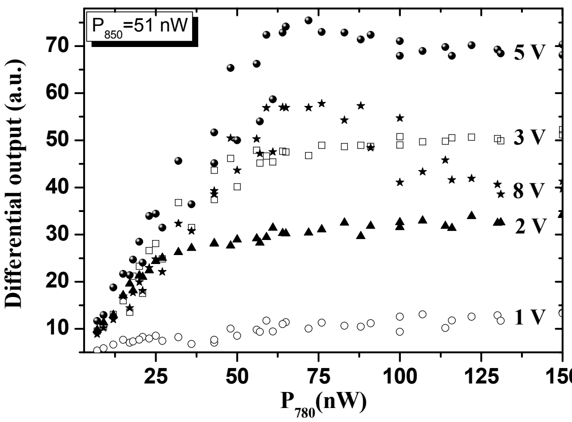

FIGURE 2. Bias voltage optimization of the device at 51 nW power of incident beams at 850 nm, to obtain maximum index of modulation and linearity span.

We can call the maximum optimum voltage as the critical voltage where the self-linearized mode of operation (negative feedback) changes to bistable mode (positive feedback) [1]. It is indicated by reduction of optical absorption at higher voltage due to the red-shift of the hh-exciton resonance to the longer wavelength than 850 nm. Figure 3 shows the increase of critical voltage with higher power of incident beams at 850 nm. It is observed through right shift of peak of the curve with higher power of incident beams at 850 nm. It was enhanced from 4.3 V at P_{850}=42 nW, to 5.8 V at 68 nW and to 10.5 V at 175 nW [2]. The increment of this voltage might be explained through nearly constant electric field strength per exciton density.

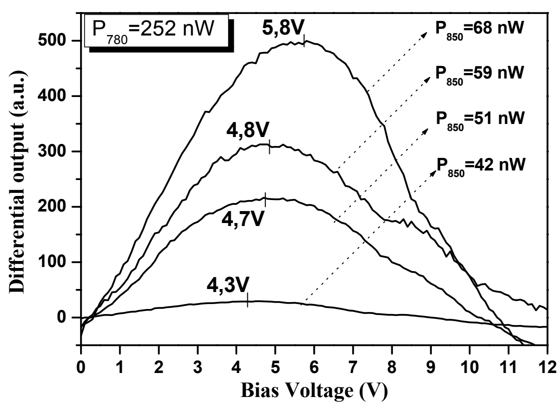

FIGURE 3. Right shift of critical voltage as a function of power of incident beams at 850 nm.

The effect of power of incident beams at 850 nm on exciton generation was verified using experimental results at Fig. 4. As can be seen, for a given injected current to differential modulators (corresponding to a given P_{780}), the density of exciton is increased linearly as a function of power of incident beams (P_{850}). The linearity ends at the comparable power of P_{780} and as the result of sufficient generated photocurrent to support the injected current, considering the same quantum efficiency for modulator and detector diodes. After that, the differential output remains steady, one thing that is impossible at injected current produced by incident beam of P_{780} ~251 nW) due to exciton saturation. It is noticeable that self-linearized mode of modulator operation is possible for differential input power of image up to 47, 112, 167, and 212 nW, applying P_{850}= 48, 98, 185 and 218 nW. However, the differential structure of processor and the steady variation of image intensity promise the proper operation of device in moderated values of P_{850} due to small injected current by detector.

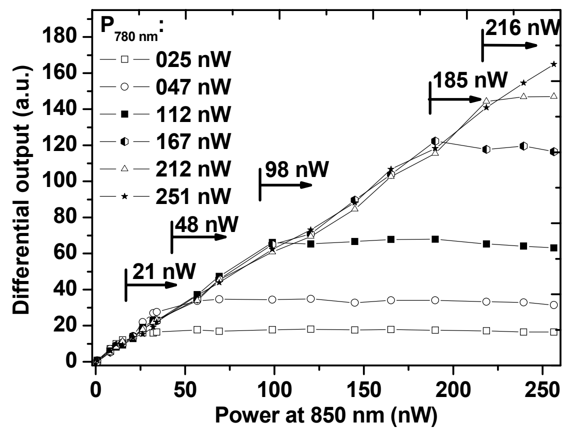

FIGURE. 4. Exciton density growth as a function of P_{850}.

In summary, the operation of image processor is optimized at reduced power of incident carrier. Results show that the linear relation between the incident power and upper level of bias voltage limit the operation at self-linearized mode.

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