Highly Sensitive VGA FEA-HARP Image Sensor

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Abstract

A 640×480 pixel image sensor consisting of 20×20-µm pixels, which consisted of an integrated field emitter array equipped with an active drive circuit and a highly sensitive avalanche-mode photoconductive target was fabricated and tested to investigate the feasibility of a high-resolution sensor with a large number of smaller pixels. Our experimental results revealed that the prototype obtained both high sensitivity due to the avalanche multiplication effect of the target and sufficient resolution as a VGA image sensor.

1. Introduction

We have been studying a flat field emitter array (FEA) image sensor with a highly sensitive, high-gain avalanche rushing amorphous photoconductor (HARP) target [1], [2], with the aim of developing high-sensitivity compact HDTV cameras. Our previous experiments on a 256×192 pixel (pixel size, 50×50-µm) FEA-HARP image sensor confirmed that the sensor obtained high sensitivity and had sufficient resolution and a wide dynamic range [3], [4]. However, for practical purposes, a high-resolution sensor with a large number of smaller pixels must be developed. A 640×480 pixel (pixel size, 20×20-µm) VGA format FEA-HARP image sensor was fabricated and tested to investigate the feasibility of the high-resolution sensor.

This paper describes the configuration and specifications of the prototype sensor. The prototype's image pick-up characteristics are also discussed.

2. Problems with previous sensor

The configuration of the previous FEA-HARP image sensor is depicted in Fig. 1. The sensor consists of a Spindt-type FEA [5], [6], a mesh electrode, and a HARP target, in close proximity to each other. The HARP target converts incident light into electron-hole pairs. The number of holes is increased by the internal avalanche multiplication effect, and a charge (hole) pattern corresponding to the optical image is formed at the electrons' scanning side of the HARP target. Electrons emitted from each pixel of the FEA are drawn to the HARP target side by the high potential of the mesh electrode, and are focused on the HARP target by a magnetic field between the FEA and the HARP target. The output signal current is obtained by recombining holes accumulated on the HARP target and scanning electrons emitted from the FEA.

The previous sensor, with 256×192 pixels, had high potential for image sensing due to its high sensitivity, sufficient resolution, and wide dynamic-range. However, because conventional passive-matrix Spindt-type FEAs are driven by applying pulses to gate-and-cathode electrode lines from external circuits, its driving speed was limited

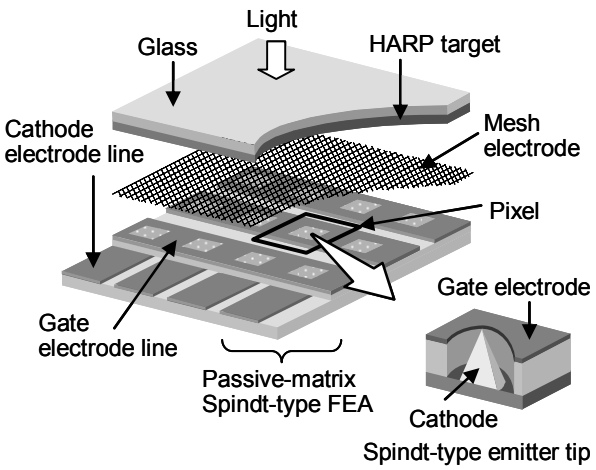

Fig. 1 Configuration of previous FEA-HARP image sensor

by a large load-capacitance between the electrode lines. A large number of interconnections between the FEA and external circuits, which was equivalent to the sum of the number of vertical and horizontal pixels, was also required to drive the FEA. These constituted limiting factors for the high-resolution FEA-HARP image sensor with a larger number of pixels.

3. Fabrication of VGA FEA-HARP image sensor

3.1 Active-matrix Spindt-type FEA

A new Spindt-type FEA with a built-in active-matrix drive circuit was developed to overcome the problems mentioned above. The configuration of this FEA is shown in Fig. 2. The active-matrix circuit consisted of pixel-select transistors in the pixel area, and vertical and horizontal scanning drivers outside the pixel area, which was fabricated on a silicon wafer using MOS-LSI technologies. The Spindt-type FEA was formed on the pixel-select transistors, and the emitter tips in a pixel and the drain of the pixel-select transistor were connected through a via plug. The gate electrode of the FEA is electrically continuous over the entire pixel area. Electrons are sequentially emitted from each pixel of the FEA by switching the pixel-select transistor in each pixel with control pulses from the vertical and horizontal scanning drivers. Figure 3 shows the circuitry of the active-matrix FEA in comparison with that of a conventional passive-matrix FEA. The active-matrix circuitry ensures high-speed operation of the FEA because the load capacitance of the active-matrix FEA is substantially smaller than that of the

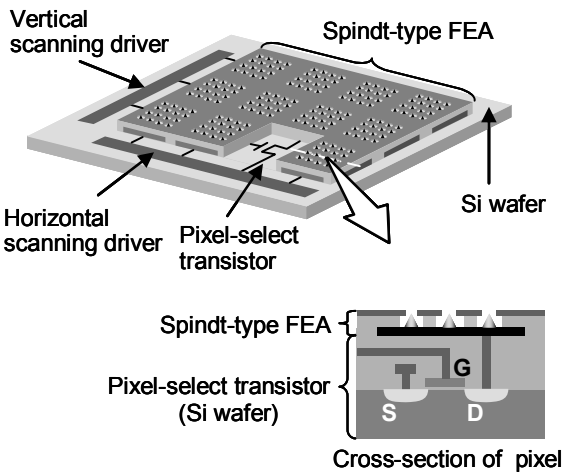

Fig. 2 Configuration of active-matrix Spindt-type FEA

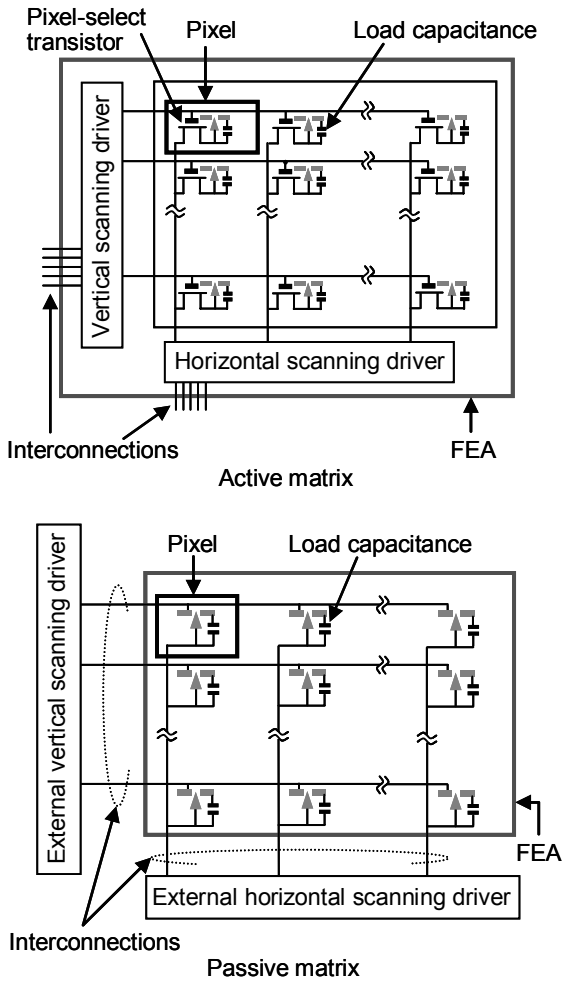

Fig. 3 Comparison of active-matrix and passive-matrix circuitries

conventional passive-matrix FEA. Moreover, because the vertical and horizontal scanning drivers are built into the FEA, the active-matrix FEA can be driven by applying several control pulses through a small number of interconnections between the FEA and the external circuits regardless of its pixel number.

Figure 4(a) is an overview of the fabricated active-matrix FEA, and (b) is a scanning electron microscope (SEM) image of a pixel. The FEA was 15×12 mm, and the pixel area was 12.8×9.6 mm. The vertical and horizontal scanning drivers were integrated outside the pixel area. The FEA had 640×480 pixels, which is equivalent to the VGA format, and the pixel size was 20×20 μm. To obtain sufficient emission current from each pixel, 121 Spindt-type emitter tips with a gate-hole diameter of about 0.8 μm were placed within a 14×14-μm area of

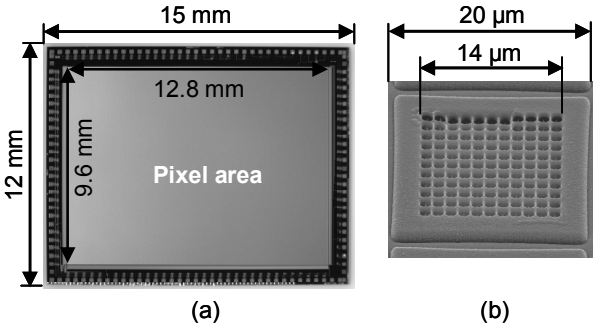

Fig.4 Fabricated active-matrix Spindt-type FEA
(a) Active-matrix FEA (b) SEM image of pixel

each pixel.

3.2 VGA FEA-HARP image sensor

Figure 5 is a photograph of the fabricated VGA FEA-HARP image sensor with the active-matrix Spindt-type FEA, which was about 10 mm thick. The distance between the FEA and the HARP target was about 2.5 mm, and the mesh electrode, which had an aperture ratio of about 45%, was midway between the FEA and the HARP target. The thickness of the HARP target was 15 μm. There were only 10 interconnections to drive the FEA, which is drastically fewer than the conventional passive-matrix 256×192 pixel FEA image sensor (with 448 interconnections) [3], [4].

4. Image pick-up characteristics of prototype

The active-matrix Spindt-type FEA of the prototype sensor was driven with pixel sequential scanning that complied with the NTSC standard. By adjusting the control pulses sent to the vertical and horizontal scanning drivers, we set the width and the interval of the equivalent drive pulses for pixel sequential scanning to approximately 0.08 μs and 1/60 s, respectively. A voltage of about 700 V was applied to the mesh electrode, and a voltage of up to 1550 V was applied to the HARP target. Moreover, a uniform magnetic field with a flux density of about 0.125 T was applied inside the prototype sensor to focus electrons emitted from each pixel of the FEA.

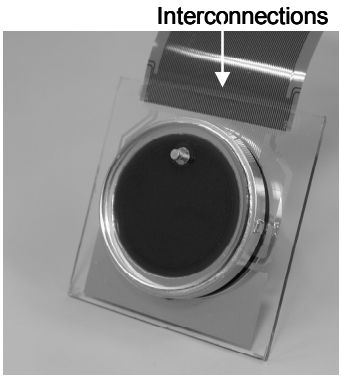

Fig.5 Fabricated VGA FEA-HARP image sensor

Fig. 6 Reproduced image taken by prototype sensor
(Illumination, of 0.3 lx,; lens iris, of F1.2)

Figure 6 is a reproduced image taken by the prototype sensor, under an illumination of about 0.3 lx and a lens iris setting of F1.2. A clear image with sufficient resolution was obtained even in lighting conditions that were as dim as moonlight.

Figure 7 plots the dependence of the output signal current on HARP target voltage. The signal current abruptly increased above the target voltage of 1200 V, indicating the presence of the avalanche multiplication effect inside the 15-μm-thick HARP target. An avalanche multiplication factor of about 200 was obtained at the target voltage of 1550 V.

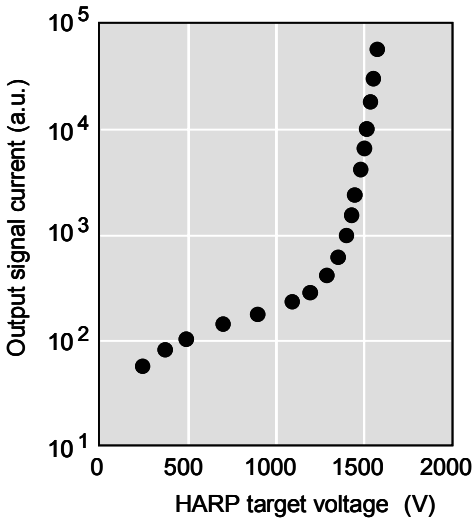

Fig. 7 Sensitivity characteristics

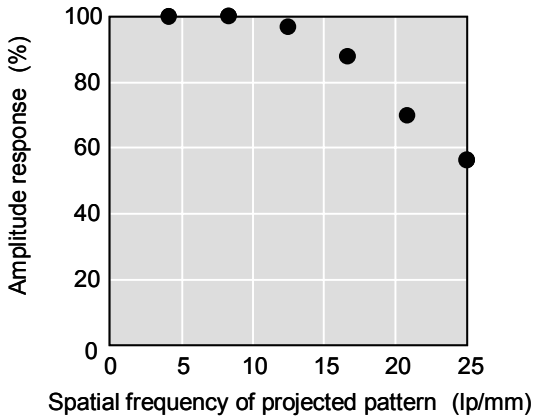

Fig. 8 Resolution characteristics

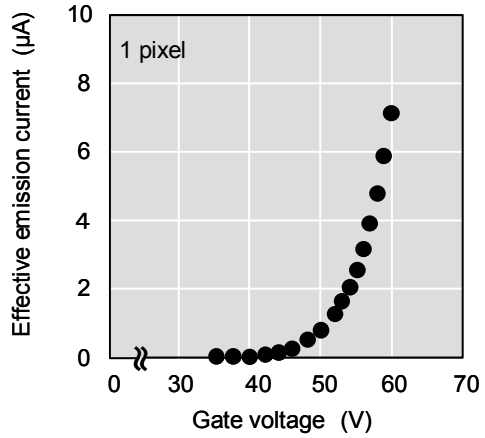

Fig. 9 Emission (dynamic range) characteristics

Figure 8 plots the resolution characteristics. The resolution was defined by the amplitude response when a black and white vertical-stripe pattern with various spatial frequencies was projected on the HARP target. The amplitude response of the prototype was about 56% at the Nyquist spatial frequency (a spatial frequency of 25 lp/mm or a stripe pitch of 20 μm), and the uniformity of resolution was good. The results demonstrate that the prototype has sufficient resolution as a VGA image sensor.

In Fig. 9, the dependence of the effective emission current on the gate voltage is indicated. The dynamic range of the FEA image sensor is determined by the effective emission current, which is defined as the current originating from electrons transmitted through the mesh electrode and reaching the HARP target. The effective emission current of the prototype was about 7 μA when the gate voltage was 60 V and the aperture ratio of the mesh electrode was about 45%. These results show that the prototype can obtain a wide dynamic range because the effective emission current required for ordinary image pick-up operation is estimated to be about 2 μA.

5. Conclusion

The goal of our work has been to develop FEA image sensors for ultrahigh-sensitivity compact HDTV cameras that can be used in various fields such as broadcasting, medicine, security, and natural sciences.

Our experimental results on the fabricated 640×480 pixel HARP image sensor with the active-matrix Spindt-type FEA revealed that the prototype sensor obtained sufficient resolution as a VGA image sensor, as well as high sensitivity and a wide dynamic range, yet offers convenient operation.

As we continue to work towards our goal, we plan to develop new FEAs with a larger number of much smaller pixels, and electro-static focusing systems.

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