Highly sensitive InGaAs/InAlAs quantum wire photo-FET

M. Ogura and T. Sugaya

An InGaAs/InAlAs quantum wire photo-FET has been fabricated on a V-grooved (311) InP substrate by atomic hydrogen assisted molecular beam epitaxy. The room-temperature photosensitivity of the quantum wire photo-FET reached 350 kA/W near a wavelength of 700 nm at a drain-source voltage of 1 V.

Introduction: The *pin* diode is the simplest of the commercially available photodetectors in terms of device structure and is suitable for application to a detector array. However, its sensitivity is limited to about 1 A/W, which is the quantum efficiency of the photo-absorption material. In such a case, the detection limit is determined by the additional electronic noise induced by the current amplifier. In contrast, an avalanche photodiode (APD) and a photo-multiplier (PMT) have higher sensitivity because of their amplification mechanism, but they are not very suitable for multi-pixel arrays because of their inferior uniformity and higher bias voltage. The bias voltages of an APD (∼100 V) and a PMT (∼1 kV) may easily damage a silicon charge amplifier within the same package if the element breaks down. A phototransistor is a good candidate for a highly sensitive photodetector. In a metal oxide semiconductor field effect transistor (MOSFET), photo-generated carriers are accumulated underneath the gate region and modulate the majority current. This device is called a photo-MOSFET and it is widely used for optically isolated relays and image sensors.

Compound semiconductor materials are essential if we are to extend the spectral range and sensitivity of photodetectors by flexibly designing the bandgap profile and achieving high carrier mobility. It is reported that high electron mobility transistors (HEMTs) have a responsivity of about 3 kA/W as a photodetector [1]. Furthermore, we have been exploiting the possibility of forming a quantum nanostructure on a patterned substrate as a cost-effective way of realising a high-performance device without high-resolution lithography [2, 3]. In this Letter, we report that a quantum wire FET has a very high responsivity of more than 100 kA/W, which is comparable to that of a PMT at a very low bias voltage of typically half a volt.

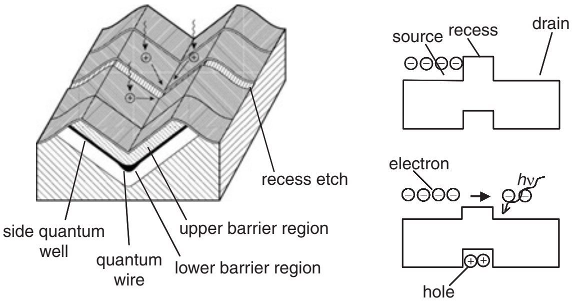

Fig. 1 *Schematic illustration and working principle of highly sensitive quantum wire photo-FET*

Experimental results: An InGaAs/InAlAs quantum wire heterostructure was grown by atomic hydrogen assisted molecular beam epitaxy (MBE) on a (311)A semi-insulating InP V-groove patterned substrate. Then, recess, source and drain contacts were formed, as shown in Fig. 1. The conduction and valence band profiles are raised at the recess because some portion of the modulation doped *n*-type region is etched off and a surface depletion region penetrates deeper into the quantum wire. This recess acts as an electron barrier and a hole trap. A gate electrode was optionally formed. The details of the growth and processing technique are described in our previous paper on quantum wire FETs [4]. Similar quantum wire FETs have also been fabricated based on the GaAs/AlGaAs system [5]. Fig. 2 shows the optical response of the InGaAs/AlInAs quantum wire. A tungsten lamp with a monochrometer and lowpass filter is employed as a light source. Monochromatic light is focused through an objective lens into an area of 15×200 µm. However, the effective sample and illumination area are limited to 2×2 µm, which is determined by the hole diffusion length and the remaining width of the structure after isolation etching. The photocurrent is normalised by the incident light power launched into the 2×2 µm sample area, which is estimated to be 8.8 pW at 700 nm. The responsivity is as high as 350 kA/W at 600–700 nm. When the surface is irradiated with light, electrons and holes are generated predominantly in the barrier region as shown in Fig. 1. Holes then accumulate in the recess of the quantum wire through side quantum wells. This is equivalent to a change in the gate bias condition and channel electrons will continue to flow for the lifetime of the hole. Therefore, one photo-generated hole at the recess of the QWR controls 350 000 electrons. This unique combination of photodiode and charge sensing amplifier is realised by self-organised growth on a patterned substrate. Fig. 3 shows the photosensitivity of the quantum wire photo-FET against source–drain voltage. The photosensitivity is more than 100 kA/W at half a volt. The response speed of the photo-FET is about 50 µs. The noise equivalent power is estimated to be 8.4×10^{-14} W/(Hz)$^{1/2}$ judging from the DC fluctuation of the lock-in amplifier.

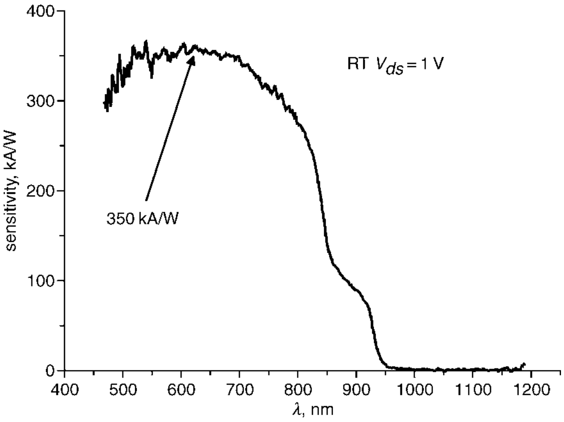

Fig. 2 *Optical response of InGaAs/AlInAs quantum wire photo-FET*

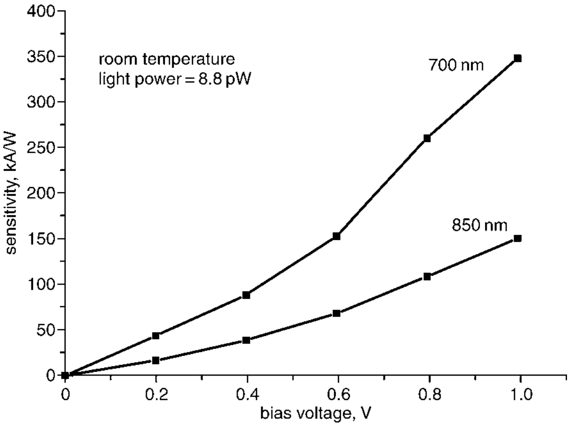

Fig. 3 *Source–drain bias dependence of InGaAs/AlInAs quantum wire photo-FET*

Conclusions: A very highly sensitive photo-FET has been realised in InGaAs/InAlAs quantum wire on a V-grooved substrate. The quantum wire FET is used as a charge-sensing amplifier embedded in barrier materials that work as photo-absorption layers. The accumulation of photo-carriers generated over a rather wide region of barrier materials into the narrow recess part of the quantum wire effectively enhances the photo-sensitivity to more than 100 kA/W at a low bias voltage, which is comparable to that of a silicon drive and a detection circuit for a hybrid sensing module.

31 January 2006
Electronics Letters online no: 20060319
doi: 10.1049/el:20060319

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