Solar-blind deep-ultraviolet photodetectors based on an $LaAlO_3$ single crystal

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Solar-blind deep-ultraviolet (DUV) photoconductive detectors based on an $LaAlO_3$ (LAO) single crystal with interdigitated electrodes are reported. The LAO detectors show a high sensitivity to DUV light with wavelengths less than 210 nm, and the DUV/UV (200 versus 290 nm) contrast ratio is more than 2 orders of magnitude. The photocurrent responsivity of LAO detector reaches 71.8 mA/W at 200 nm at 10 V bias, and the corresponding quantum efficiency η is 44.6%. The noise current under sunlight at midday outdoors is only 77 pA. The experimental results indicate that the LAO detectors have attractive potential applications in DUV detection. © 2009 Optical Society of America

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Solar-blind deep-ultraviolet (DUV) photodetectors with excellent thermal stability and reliability have attracted a strong interest owing to their broad potential applications in the fields of automatization, short-range communications security, biological researches, and military services. In particular, solar-blind DUV detectors can work in a harsh environment of sunlight radiation. DUV photodetectors fabricated from various wide-bandgap materials, such as *c*BN [1], $Al_xGa_{1-x}N$ [2], diamond [3], and II–IV compounds [4], have been reported. However, the fabrication processes for the DUV photodetectors mentioned above are complex and costly.

Perovskite oxides have drawn much attention during the past decades for their abundant properties, such as dielectric, piezoelectric, ferroelectric, ferromagnetic, superconducting, and optical characteristics. Photoelectric effect, as one of the most important properties, has been studied by several research groups [5–13]. $LaAlO_3$ (LAO), one of the perovskite oxide materials, is an insulator with a bandgap of $\sim$5.6 eV [14]. It has a very good chemical and thermal stability and often has been chosen as a substrate or buffer layer for growing high-temperature superconductors. In addition, LAO has been paid much attention as a promising alternative gate-dielectric material [15]. UV photoelectric effects in tilted LAO single crystal and amorphous $LaAlO_{2.73}$/Si heterostructure have been reported in our previous work [16,17]. However, as far as we know, solar-blind DUV photodetectors based on an LAO single crystal has not yet been reported. In this Letter, we will report on solar-blind DUV photodetectors based on an LAO single crystal with interdigitated electrodes. The photocurrent response reaches 71.8 mA/W at 200 nm, and the noise current under sunlight is 77 pA at 20 V bias at ambient temperature.

The LAO single crystal used in the present study is the as-supplied LAO (001) substrates with purity of 99.99% and a mirror double polished. The size of the LAO wafer is 5×10 mm^2 with a thickness of 0.5 mm. Figure 1 shows the schematic of a typical LAO photodetector. An Au layer with 100 nm thickness was deposited onto one surface of the LAO wafer by electron-gun evaporation. Conventional UV lithography and etching were performed to fabricate Au interdigitated electrodes. The effective area of the photodetector is 2×6 mm^2. The finger width w of the electrodes is equal to the separated spacing s. The ranges of w and s are from 5 to 50 μm for different detectors. Owing to the shadowing effect of electrodes, the active area (the area directly exposed to radiation) is 2 mm^2.

A 30 W D_2 lamp was employed to act as a light source, and the light intensity was calibrated by a UV-enhanced silicon photodetector in the wavelength range of 200–400 nm. The photoelectric signal was recorded by a 500 MHz digital oscilloscope with a sampling resistance of 1 MΩ. The spectral responsivity was measured using a monochromator combined with an optical chopper and a lock-in amplifier.

Figure 2 shows the steady-state photocurrent of an

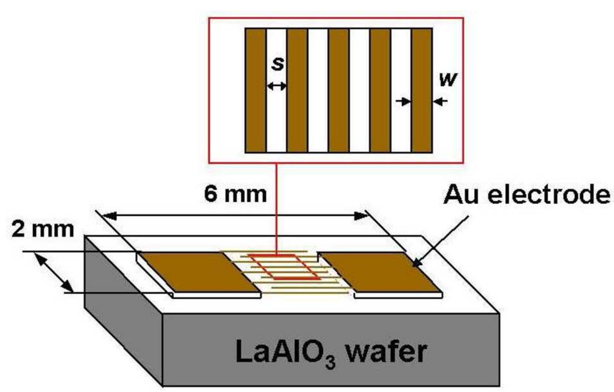

Fig. 1. (Color online) Schematic diagram of the $LaAlO_3$ photodetector with interdigitated electrodes; w is the finger width and s is the interspacing of the interdigitated electrodes.

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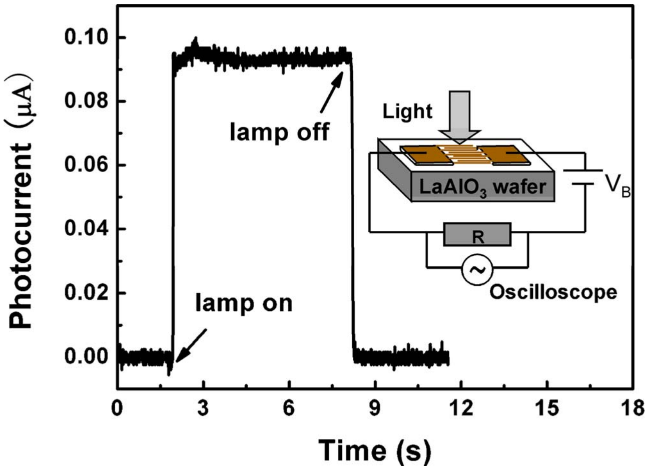

Fig. 2. (Color online) The steady-state photocurrent of the $LaAlO_3$ photodetector with 5 μm finger width under illumination of the D_2 lamp at 10 V bias. The inset shows the schematic of measurement circuit.

LAO detector with a finger width of 5 μm under irradiation of the D_2 lamp. The schematic of the measurement circuit is shown in the inset of Fig. 2. The bias V_B is a tunable dc voltage source. The LAO detector is in series with a sampling resistance R. A change in voltage developed across R was recorded by the oscilloscope. The photocurrent in the bias circuit can be calculated by the voltage divided by the sampling resistance. As shown in Fig. 2, the photocurrent was high (low) when the D_2 lamp was on (off). The photocurrent was 0.977 μA at 10 V bias. The mechanism of photocurrent response of the LAO detector to the illumination of the D_2 lamp is not difficult to understand. Because the photon energies, corresponding to the wavelengths less than 210 nm from the D_2 lamp, are higher than the bandgap of LAO, the LAO single crystal absorbed the incident photons and generated electron-hole pairs. The photogenerated electrons and holes were separated by the electric field of supplied bias and then formed photocurrent.

Figure 3(a) shows the bias dependence of the photocurrent for different LAO detectors with finger widths of 5, 10, and 20 μm. We can find that the photocurrent increased linearly with bias for all the LAO detectors with different w and s. Figure 3(b) illustrates the variation of photocurrent of the LAO detectors as a function of the finger width and spacing at different biases. It can be seen that the reduction of finger width w and interspacing s largely enhanced the photoelectric responsivity of LAO detectors, since the recombination of photogenerated carriers was reduced and more carriers can be collected for the detector with narrower finger width and interspacing. After carefully fitting the experimental data, we got a relationship of photocurrent $\propto w^{-2}$ [solid curves in Fig. 3(b)], which agrees well with the theory of photoconductive detectors [18,19].

Figure 4 shows the spectral response of the LAO detector with 5 μm finger width at 10 V bias at ambient temperature. The LAO detector shows a high sensitivity to DUV light with a wavelength less than 210 nm. The photocurrent responsivity reaches

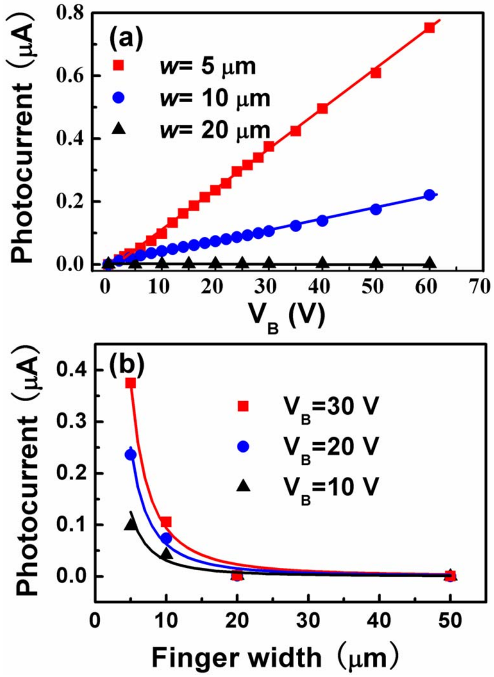

Fig. 3. (Color online) (a) Bias dependence of the photocurrent for $LaAlO_3$ detectors with different finger width. (b) Variation of the photocurrent as a function of the finger width at different biases.

71.8 mA/W at the wavelength of 200 nm. The quantum efficiency is 44.6%, according to the formula $\eta = R_i h\nu/q$, where R_i is the photocurrent responsivity of the photodetectors, h is the Planck constant, ν is the frequency of incident light, and q is the charge of one electron. The sharp cutoff wavelength of the spectrum is at 220 nm, which corresponds to a photon energy of 5.6 eV, agreeing well with the LAO bandgap and demonstrating a bandgap excitation process. The DUV/UV (200 versus 290 nm) contrast ratio is more than 2 orders of magnitude, indicating that the LAO detector has an intrinsic solar blindness. The inset in Fig. 4 shows the dependence of photocurrent of LAO detector with 5 μm finger width on the incident light

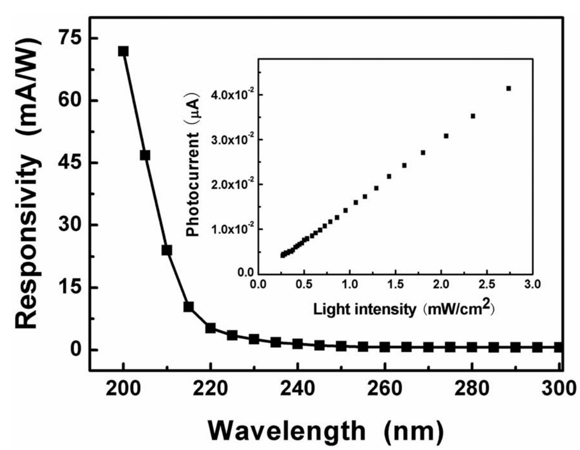

Fig. 4. Spectral response of the $LaAlO_3$ detector with a finger width of 5 μm at 10 V bias. The inset is the photocurrent variation with the incident light intensity of the D_2 lamp.

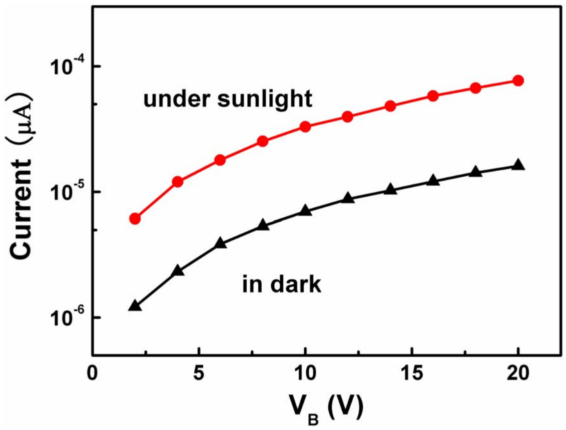

Fig. 5. (Color online) Bias dependence of the current of the $LaAlO_3$ detector with a finger width of 5 μm measured in the dark and under the irradiation of sunlight at midday.

intensity of the D_2 lamp at 10 V bias. The photocurrent has a good linear relationship with the light power density.

Furthermore, we measured the dark current and the noise current directly under the illumination of sunlight at midday outdoors using a Keithley Model 2182 nanovoltmeter. As shown in Fig. 5, the noise current of the LAO detector with 5 μm finger width under sunlight is 77 pA, and the dark current is 25 pA at 20 V bias, which suggest that the LAO detector can directly detect DUV light without any filters to block the sunlight.

In conclusion, we have successfully fabricated solar-blind DUV photodetectors based on an LAO single crystal with interdigitated electrodes. The detectors show a high sensitivity to DUV light and a high signal-to-noise ratio. The spectral response has a sharp cutoff wavelength at 220 nm, with an obvious rejection ratio (200 versus 290 nm) more than 2 orders of magnitude. The photocurrent responsivity is 71.8 mA/W at 200 nm, and the corresponding quantum efficiency reaches 44.6%. In particular, the noise current under sunlight is only 77 pA at 20 V bias. In addition, the present DUV detectors are based on a commercial LAO single crystal and do not need a complex fabrication process. The excellent characteristics of LAO detectors demonstrate its potential and attractive applications in DUV detection.

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