Supporting Information

Ultraviolet wavelength identification using energy distribution of hot electrons
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S1. The photocurrent and dark current of the wavelength detectors with different insulator thicknesses are shown in Figure S1. With increasing the insulator thickness from 20 to 60 nm, the photocurrent decrease slightly from 2.9 to 1.5 nA. However, as the thickness increase from 40 to 60 nm, the dark current almost overlap each other, the current oscillates between -100 and 100 fA, which indicates that the dark current have reach or even beyond the accuracy of the test system.

Figure S1. (a) The photocurrent and dark current of the wavelength detectors with different insulator thicknesses. (b) The dark current of the wavelength detectors with different insulator thicknesses.
S2.

The dark current of the metal/oxide/silicon originates from many dielectric conduction mechanism, such as the Fowler-Nordheim tunneling, Poole-Frenkel tunneling, direct tunneling or Schottky emission. Normally, for the thick oxide (larger than 5 nm), Fowler-Nordheim tunneling is considered as the dominant conduction mechanism at very high fields on the order of 7 to 8 MV/cm\(^1\) and the Poole-Frenkel (PF) tunneling would dominant the conduction mechanism when the electrical fields in oxide is below 1 MV/cm. In this work, the applied electrical fields is around 1 MV/cm, therefore the PF tunneling is more suitable to predict the dark current of the Al/SiO\(_2\)/Si junctions\(^2\).

The FP tunneling current of MOS junction can be expressed as\(^3\):

\[
I = CAE e^{-(q\Phi - \beta \sqrt{E})/kT}
\]

Where \(C\) is a proportionality constant. \(A\) is the area of the junction, which is about 1mm\(^2\) in this work, \(E\) is the applied electrical field, \(E=V/d\), \(V\) and \(d\) is the applied voltage and the SiO\(_2\) thickness, respectively. \(q\Phi\) is the ionization potential in eV, which is the amount of energy required for the trapped electrons escaping from the influence of the positive nucleus from the trapping center in oxide when no field is applied, \(q\Phi\) is typical ~1 eV for SiO\(_2\). \(\beta\) is a material parameter, depending on the dielectric constant, \(\beta = (q^2/\pi \varepsilon_0 \varepsilon_r)\), \(\varepsilon_0\) is the dielectric permittivity of free space, the low-frequency dielectric constant \(\varepsilon_r\) is 3.9 for SiO\(_2\). \(\xi\) varies between one to two, depending on the amount of acceptor compensation, in this work, we assume the SiO\(_2\) are not compensated and the \(\xi=2\).\(^3\)

Figure S2 shows the calculated dark currents of Al/SiO\(_2\)/Si junction with different SiO\(_2\) thicknesses. With a constant of \(C=10^{11}\), the simulation result were consistent with the experimental measurements for dark current of Al/SiO\(_2\)/Si junction with 20 nm thickness. The dark current of Al/SiO\(_2\)-40 nm/Si is lower than \(5 \times 10^{-15}\) A at +4 V. It needs to be noted that the dark current is sensitive to the material quality of the SiO\(_2\) layer, therefore, more accurate dark current should be further confirmed by test system with higher-accuracy and lower noise in the future.

![Figure S2. The calculated I-V curves of Al/SiO\(_2\)/Si junctions with different SiO\(_2\) thicknesses using the Poole-Frenkel tunneling model.](image-url)
S3. The normalized I-V curves of the Al/SiO$_2$/Si junction over a wavelength range of 285 - 292 nm are shown in Figure S3, the illumination power is kept at 60 µW. By distinguishing the shape of the normalized I-V curves, wavelength identification with a resolution of 1 nm can be achieved.

**Figure S3.** (a) Normalized I-V curves over a wavelength range of 285 - 292 nm at illumination power of 60 µW. (b) The details of the normalized I-V curves over the wavelength range of 285 - 292 nm at voltage 2 V. The wavelength can be clearly identified by the normalized I-V curves.
S4. Linear power dependence of photocurrent at 4 V as a function of power at the two wavelengths, 290 and 320 nm, respectively.

**Figure S4.** Power dependence of photocurrent at 4 V as a function of power at the two wavelengths, 290 and 320 nm, respectively.
The current ratios $I_2/I_4$ of the Al/SiO$_2$/Si junction are almost power-independent at 290 and 320 nm respectively. In addition, with the wavelength decreasing from 320 to 290 nm, $I_2/I_4$ increases from 0.25 to 0.39.

**Figure S5.** Power-independent current ratio $I_2/I_4$ at 290 and 320 nm respectively. $I_2/I_4$ increases from 0.25 to 0.39 with the wavelength decreasing from 320 to 290 nm.
S6. The wavelength identification can be realized by measuring the normalized I-V curves or current ratio of Al/SiO$_2$/Si junction at any two voltages. Moreover, any voltage can serve as the standard, such as 3 and 8 V.

**Figure S6.** (a) The normalized I-V curves with 3 V as the standard. (b) The current ratio $I_x/I_3$, where $I_x$ and $I_3$ are the photocurrent at voltage of $x$ and 3 V, where $x$ is smaller than 3. (c) The normalized I-V curves with 8 V as the standard. (d) The current ratio $I_x/I_8$, where $I_x$ and $I_8$ are the photocurrent at voltage $x$ and 8 V, where $x$ is smaller than 8. It can be seen that the normalized I-V curves and the current ratios with any voltage as the standard are valid to identify the wavelength.
S7. Due to the non-optimized device capacitance and the relatively high parasitic resistance from the thin Al layer and Si semiconductor substrate, the response time of the wavelength detector is only about 100 ms, as shown in Figure S7. However, the internal photoemission process in the hot electrons photodetectors is typically ultrafast with timescale of < 1 ps, so it can be reasonably expected that the response frequency of our photodetector can be greatly improved after optimizing the device structure and the electrode design.

**Figure S7.** The time response characteristics of the Al/SiO$_2$(40 nm)/Si junctions under 290 nm illumination at +4 V.

**REFERENCE**

1. Lenzlinger, M.; Snow, E. H., Fowler-Nordheim Tunneling into Thermally Grown SiO$_2$. *Journal of Applied Physics* 1969, 40 (1), 278-283.
2. Harrell, W. R.; Frey, J., Observation of Poole-Frenkel effect saturation in SiO$_2$ and other insulating films. *Thin Solid Films* 1999, 352 (1-2), 195-204.
3. Yeargan, J. R.; Taylor, H. L., The Poole - Frenkel Effect with Compensation Present. *Journal of Applied Physics* 1968, 39 (12), 5600-5604.