# Analysing the sensitivity of a photosensor based on $MoS_2$ TFET for visible light detection


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***Abstract*—In this work, a novel $MoS_2$-based tunnel field-effect transistor photosensor is introduced for detecting visible light. A portion of the channel material serves as the light-sensitive region, inducing additional electron-hole pairs upon light exposure, thus generating a photovoltage, leading to enhanced tunneling. The device exhibits an ON current of around $10^{-5}$ A/$\mu$m and an OFF current of around $10^{-18}$ A/$\mu$m. To assess its photosensitivity, various wavelengths ranging from 400 nm to 700 nm within the visible spectrum were examined, yielding a corresponding responsivity of approximately $10^4$ A/W and a quantum efficiency exceeding $> 50\%$. These promising results mark the device in the category of next-generation low-power photosensor.**



***Index Terms*—TFET, photosensor, $MoS_2$, responsivity, QE**


## I. INTRODUCTION

In the field of integrated optoelectronic platforms, photodetectors utilizing field-effect transistor (FET) technology offer numerous benefits when compared to traditional photodetection. These advantages include its compatibility with CMOS technology, its ability to scale effectively, and its exceptional efficiency in power consumption. Moreover, from a device perspective, FET based photodetectors offer higher ON current, lower dark current, higher ON/OFF current ratio, etc. Exploration of FETs based photodetector has gained considerable interest in recent years, with a primary focus on enhancing the photoresponse by modulating device configuration, material, physics, etc. In this context, optically controlled tunnel field effect transistors have gained a lot of attention in recent years due to their extremely low subthreshold swing (SS) and off state current. Further, it has been highlighted that low SS is the reason behind the higher photosensitivity of TFET based photosensors [1]. Recently, there has been a concentrated effort in studying atomic mono-layer materials, recognizing their vast potential across electronic and optoelectronic domains. Two-dimensional transition-metal dichalcogenides (TMDs) become an alternative to graphene because of their sizable bandgap in the field of nanoelectronics. Among various TMDs such as $MoS_2$, $MoSe_2$, $MoTe_2$, $WS_2$, and $WSe_2$, the abundantly available molybdenite refers to the $MoS_2$. In its monolayer form, $MoS_2$ emerges as a semiconductor possessing a direct bandgap of 1.8 eV . This characteristic is particularly compelling as it addresses a significant drawback of graphene, which lacks a bandgap, thus paving the way for 2D materials to revolutionize the next generation of switching and optoelectronic devices [2]. $MoS_2$ has made notable strides in various domains, notably energy conversion, energy storage, and the hydrogen evolution reaction. Moreover, $MoS_2$ exhibits intriguing properties when configured with an odd number of layers, generating oscillating piezoelectric voltage and current outputs.

This study mainly focuses on integrating the benefit of $MoS_2$ and TFET in a photosensor. The atomic thickness of $MoS_2$ enables superior gate control, thereby enhancing the overall performance of devices. When exposed to light of various wavelengths within the visible range, the $MoS_2$ flake induces the generation of excess electron-hole pairs in the silicon near the tunneling region, leading to a reduction in the tunneling width of the device. This in turn increases the ON current of the device and also the steepness. At the same time, the presence of the top gate near the drain side maintains the OFF as well as the ambipolar current of the device.

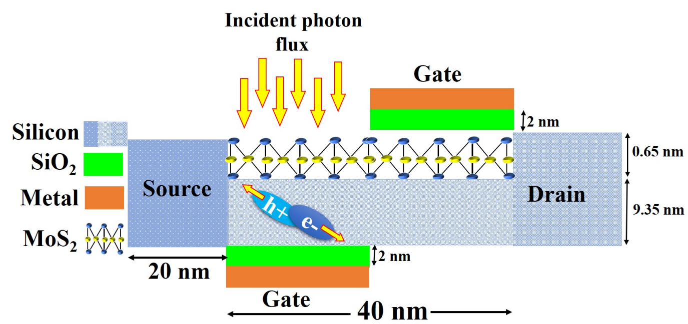


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Fig. 1. Schematic of $MoS_2$ channel based TFET photosensor

## II. DEVICE DESIGN AND SIMULATION SETUP

The proposed device is shown in Fig.1 indicating all dimensions. The source and drain consist of heavily doped silicon material, facilitating the design of the n-type n-TFET. The channel comprises two materials: a single layer of $MoS_2$ on top, where light illumination occurs, and lightly doped silicon at the bottom. The gate positioned near the source-channel tunnelling region is located at the bottom, while the gate

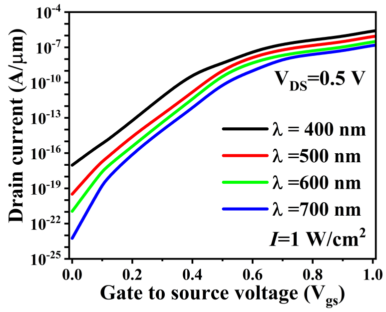


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Fig. 2. Transfer characteristics of the proposed $MoS_2$ channel based TFET photosensor

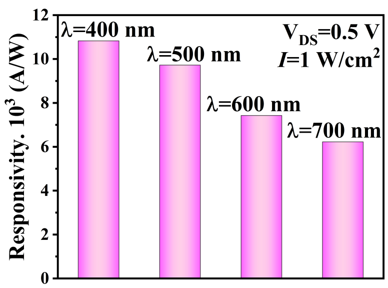


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Fig. 3. Responsivity of the $MoS_2$ channel based TFET photosensor

near the drain region is positioned at the top. The device is able to obtain an ON current of $2.514\text{x}10^{-5}\text{A}/\mu\text{m}$ OFF current of $9.464\text{x}10^{-18}\text{A}/\mu\text{m}$ exhibiting a ON/OFF current ratio of $2.65\text{x}10^{12}$. For the simulation, we used the sentaurus TCAD simulator, with specific models of optical generation in the physics file. For simulating $MoS_2$ material, a separate parameter file is generated in the tool.

## III. Results and Discussion

In this section, various analysis have been conducted on the performance of the $MoS_2$ channel-based TFET photosensor, examining its efficiency across a spectrum of visible wavelengths. In response to light of a particular wavelength and intensity, the device generates excess electron-hole pairs. Applying a gate voltage ($V_{gs}$) then separates these excess electron-hole pairs, producing additional voltage within the device. The emergence of this additional voltage, termed as photovoltage, is attributed to the light. Consequently, when combined with $V_{gs}$, this photovoltage effectively reduces the tunneling barrier, further compared to tunneling solely induced by the gate voltage. This facilitates increased tunneling from the source valence band to the channel conduction band. Therefore, the electrostatic potential of the tunneling gate shifts, altering the channel potential in response to light. This dynamic accounts for the elevated sensitivity of such photosensors.

Fig. 2 represents the variation of the drain current of the device for different wavelengths ($\lambda = 400nm - 700nm$ ) for an incoming optical power intensity (I) of 1 W/cm2. As the $\lambda$

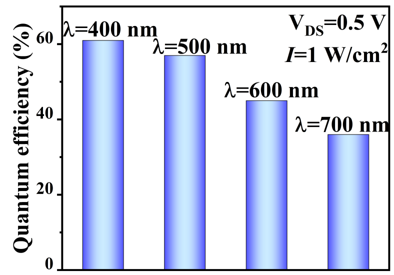


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Fig. 4. Quantum efficiency (QE) of the $MoS_2$ channel based TFET photosensor

increases the current decreases, this is due to the inverse relationship of $\lambda$ with optical power. At $\lambda = 400nm$ the photon absorption rate of the photosensor is highest and as $\lambda$ increases this rate decreases. At a $\lambda = 400nm$, the photosensor exhibits the highest photon absorption rate, which gradually decreases as the wavelength increases. Shorter wavelengths correspond to higher energy, resulting in increased photon absorption and the generation of a larger number of EHPs.Corresponding responsivity and QE, which are critical parameters defining the photosensor's performance, are illustrated in Fig 3 and Fig 4. Responsivity gauges how effectively incident light is transformed into an electrical signal, calculated by dividing the photocurrent by the incident optical power. Similarly, QE indicates the generation of EHPs per incident photon within a specified illuminated area. It's evident that in the proposed photosensor, lower wavelengths result in higher values of responsivity and QE. This occurrence stems from the greater optical energy associated with lower wavelengths, which in turn yields larger quantities of EHPs and drain current. The heightened responsivity and QE of the proposed photosensors indicate their ability to detect low-intensity light with heightened sensitivity.

## IV. Conclusion

This work described a highly sensitive TFET photosensor utilizing TMD materials. Notably, the device utilizes the channel region near the source for light illumination, resulting in the generation of excess electron-hole pairs (EHPs) and consequently higher photocurrent. With a high responsivity and quantum efficiency (QE), along with a notable ON current, this photosensor underscores the versatility of TMD materials in expanding the potential applications of optical devices across the visible spectrum. However, the spectral photoresponse can be modulated outside the visible range of wavelength by substituting silicon with semiconductors possessing appropriate bandgaps.

## References

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