Supplementary Information

Bi_2O_2Se-Based Integrated Multifunctional Optoelectronics

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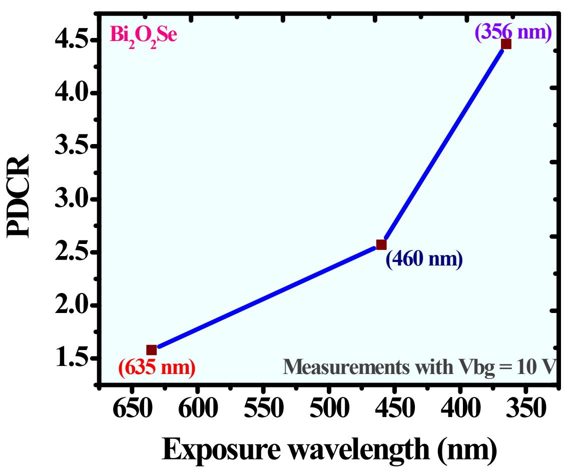

Figure S1: Photo-to-dark current ratio (PDCR = I_{ph}/I_{dark}, where $I_{ph} = I_{llumination} - I_{dark}$) with wavelengths of 635 nm (PDCR = 1.579), 460 nm (PDCR = 2.571), and 365 nm (PDCR = 4.464). The dark current at V_{bg} = 10 V is 8.56 μA.

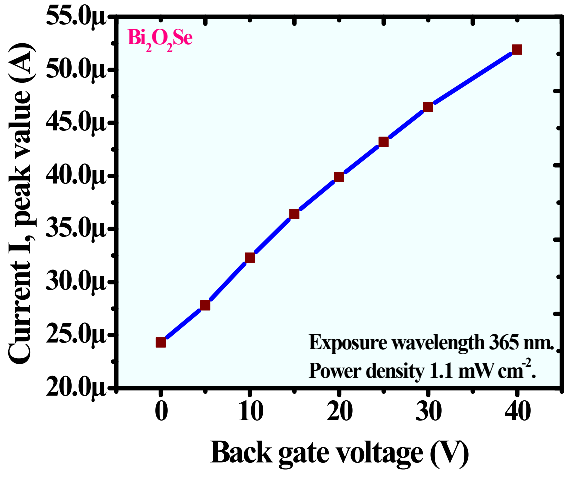

Figure S2: Back gate voltage has a significant effect on the current (I_d). As the back gate voltage increases, the response current also increases, showing the peak values of current at different back gate voltages.

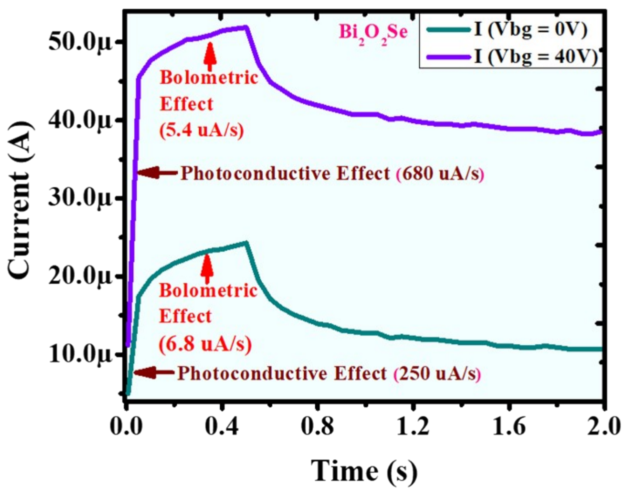

Figure S3: The bolometric effect in the absence of a back gate voltage (V_{bg} = 0 V) and with an applied back gate voltage (V_{bg} = 40 V). The exposure wavelength was 365 nm with an optical power density and duration of 1.1 mW cm^{-2} and 500 ms, respectively.

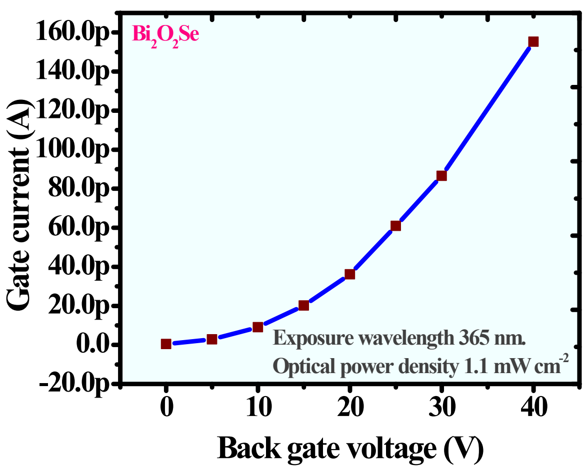

Figure S4: Gate current variation with applied back gate voltage. As the back gate voltage increases (0 V to +40 V), the gate current also increases.

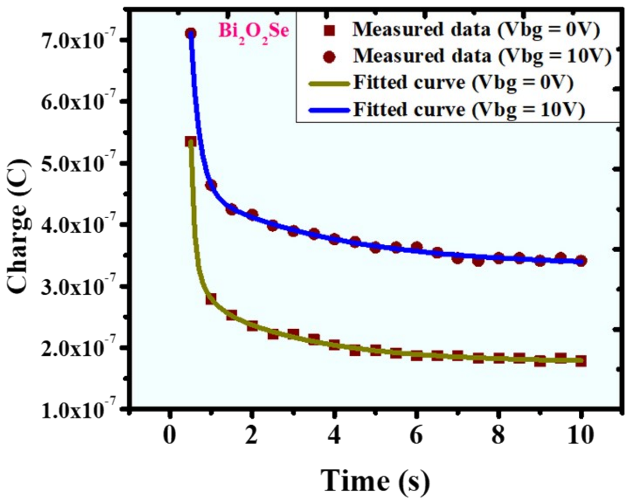

Figure S5: Represents the decay of photogenerated charge with and without back gate voltage. When a back gate voltage is not applied (V_{bg} = 0 V), the charge decays in less time, while with a back gate voltage (V_{bg} = 10 V), the decay of charge becomes slow; hence, the charge remains trapped for a longer period of time (storing the information).

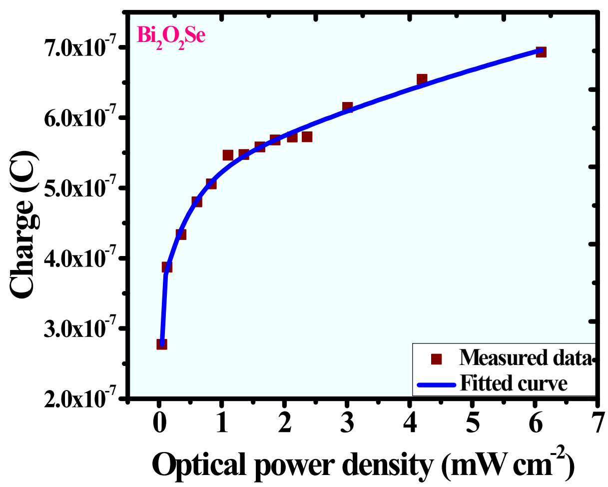

Figure S6: The photogenerated charge depends upon the optical power density. As the optical power density increases, the amount of charge generated also increases (brown blocks show measured values, while the graph in blue is the fitted curve).

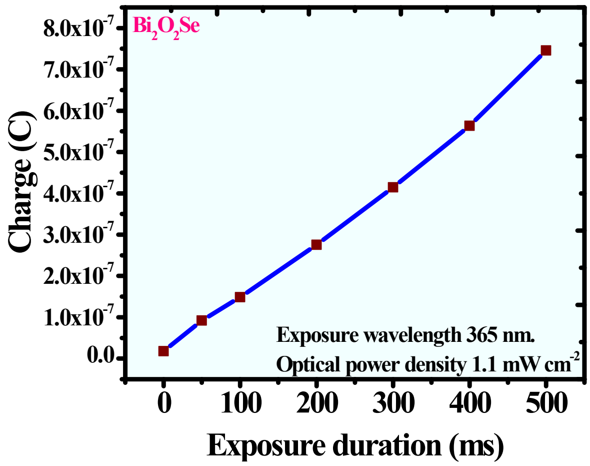

Figure S7: The photogenerated charge depends upon the dose (duration) of optical power. As the duration of optical power (with a constant optical power density of 1.1 mW cm^{-2}) increased, the amount of charge increased significantly.

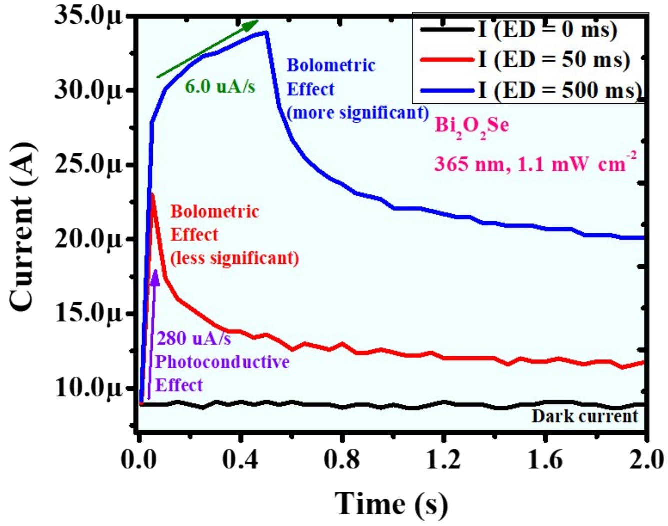

Figure S8: When the exposure duration is low (50 ms for the curve in red), the bolometric effect is less significant, and when the exposure duration is increased (500 ms for the curve in blue), the bolometric effect becomes more significant.

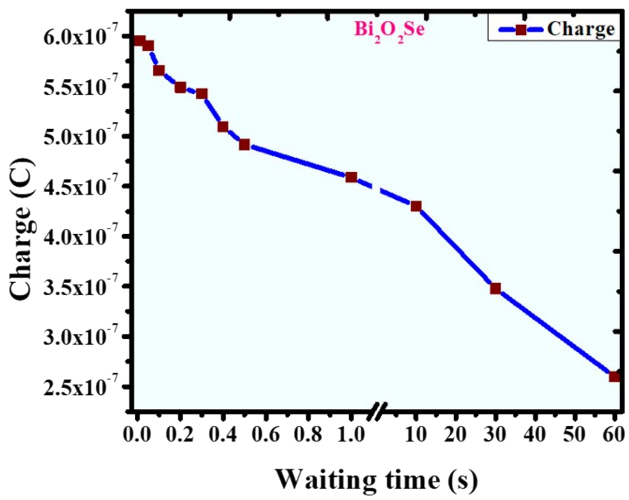

Figure S9: The waiting time is one of the factors influencing the decay of charge. The photogenerated charge decreases as the waiting time increases (brown points represent measured values). In the period from 0 to 1.0 s, the decay of the charge was measured in small time differences, and a slow decay of charge was found.

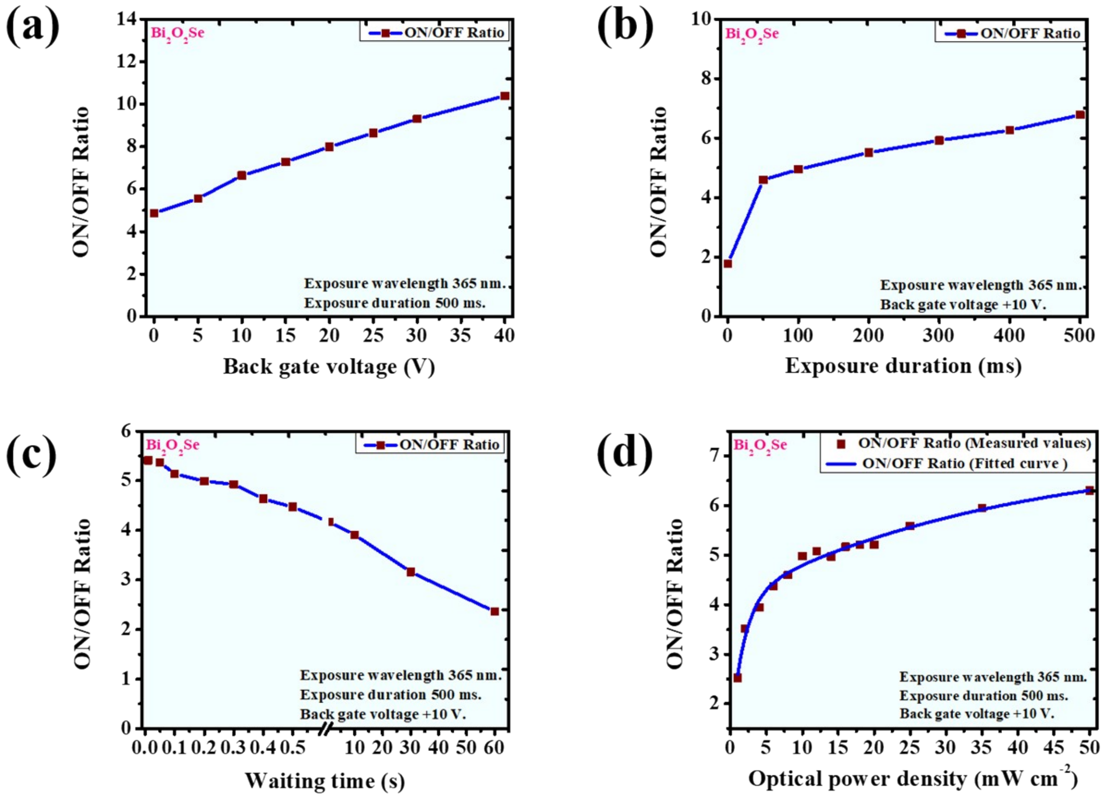

Figure S10: Represents ON/OFF ratio. Figure S10-a shows that as the back gate voltage (V_{bg}) increases from 0 V to 40 V, the ON/OFF ratio increases from ~5 to ~10. This is due to higher V_{bg} leading to enhanced trapping sites (into the trapping layer), which results in a higher response current after exposure. Figure S10-b represents the ON/OFF ratio with respect to the exposure duration. A higher exposure duration produces more charge carriers, which increases the ON/OFF ratio. Figure S10-c infers that a higher waiting time causes a decay in the ON/OFF ratio. Figure S10-d shows that the optical power density (OPD) has a positive effect on the ON/OFF ratio, which increases with the OPD.

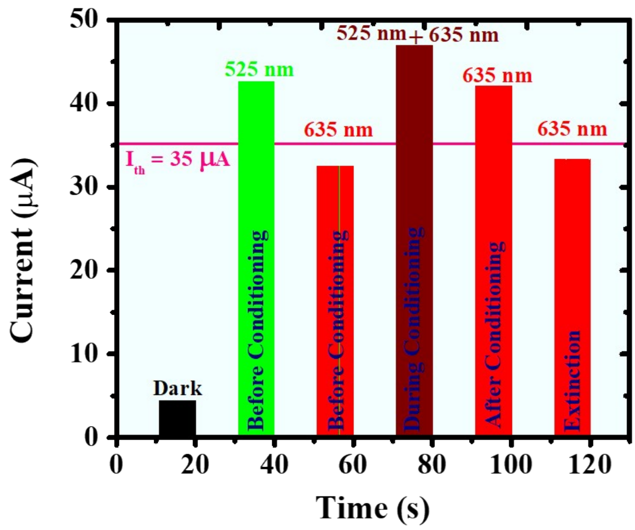

Figure S11: Represents a comparative view of the current level throughout the demonstration of the conditioned learning process. The dark current level was 4.4 μA. Before conditioning, the current level was 42.6 μA (after 10 consecutive pulses of US, 525 nm), higher than threshold current level (35 μA). On application of NS (635 nm) The current level was 32.5 μA (after 10 consecutive pulses), which was lower than the threshold current level (35 μA). During conditioning, the current increases to 47.0 μA (10 consecutive pulses, 525 nm and 635 nm simultaneously), which was higher than the threshold current level (35 μA). After conditioning, the current level for NS→CS was 42.1 μA (10 pulses, 635 nm) higher than the threshold current level (35 μA), showing the conditioned response. After a delay of 90 sec, an extinction behavior was observed with the current level for CS→NS 33.3 μA (10 pulses, 635 nm), which was lower than the threshold current level (35 μA), showing no conditioned response (forgetting).

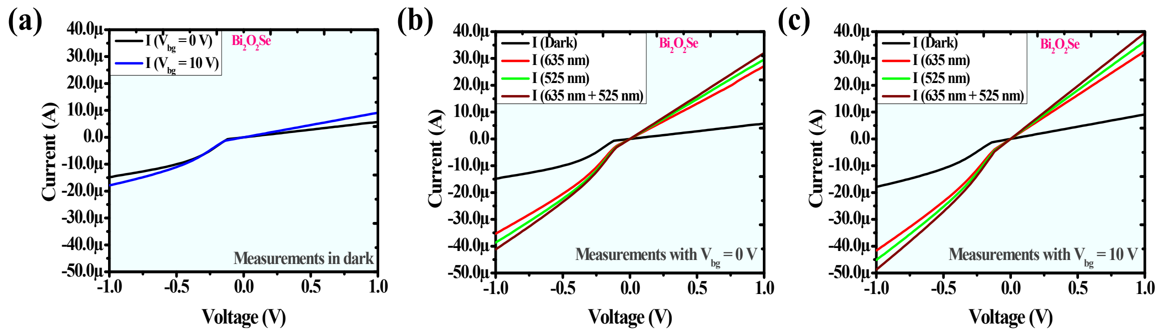

Figure S12: Variation in current with applied back gate voltage in dark conditions and under exposure conditions [V_{ds}: -1.0 V to 1.0 V]. (a) shows that the effect of back gating increases the level of drain current. The current increases due to exposure to 635 nm, 525 nm, and both light wavelengths (635 nm + 525 nm) without back gate voltage (b) and with back gate voltage (c).

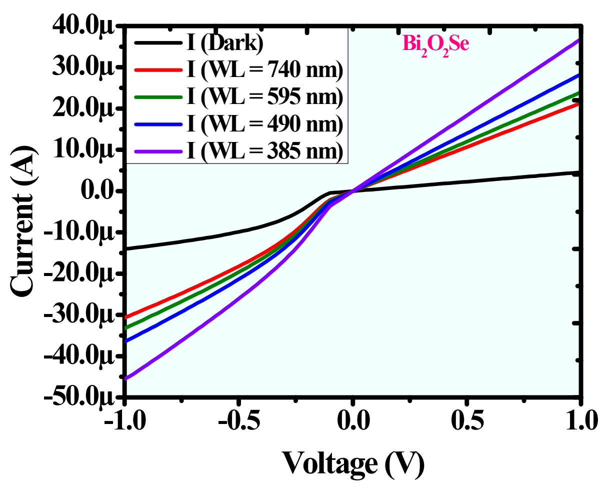

Figure S13**:** Variation in current with applied voltage (-1.0 V to 1.0 V) in dark condition and with exposure conditions. The current increases significantly under exposure to wavelengths of 740 nm, 595 nm, 490 nm, and 385 nm.

Table S1**:** A brief comparison with major reported references for optoelectronic memory process based on 2D materials.

Reference → Parameters of comparison↓	Ref-19	Ref-20	Ref-21	Ref-22	This work
1. Process of material synthesis	Transfer from bulk.	Mechanical exfoliation, CVD	Mechanical exfoliation, CVD	CVD	LPCVD
2. Active material	MoS_2 – single layer	CuIn7Se11 (CIS) – few layer InSe – few layer MoS_2 – single layer	MoS_2 – Graphene	MoS_2 – single layer	Bi_2O_2Se (6 layers)
3. Trapping medium	AuNPs	Active material itself	-----------	Treated SiO_2	SiO_2
4. Gate voltage (Vg)	10 -100 V	80 - 90 V	50 V	80 V	10 V
5. Gate leakage current	-----------	140 pA	-----------	-----------	10 pA
6. Optical power density	0.1-1000 µW cm^{-2}	150 mW cm^{-2}	37.6 mW cm^{-2}	19 nW cm^{-2}	1.1 mW cm^{-2}
7. Optical Wavelength	655 nm	543 nm	655 nm, white light	450 nm, 650 nm	365 nm (UV)
8. Exposure duration	1000 ms	~1 sec.	30-100 ms	1 sec	500 ms
9. Waiting time	-----------	0.9 sec. (for InSe)	-----------	500 ms	500 ms
10. Output current	10^{-7}-10^{-4} A	~32.0 µA	X100 µA	7.7 nA	22.0 µA
11. Drain voltage (Vds)	10 V	10.0 V	0.1 V	3.0 V	1.0 V
12. Other application reported	Multibit memory.	Memory array for image capture.	Multifunctiona l.	Multibit operations.	Associative learning, Logic gate operation, binary to decimal conversion.