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# Supplementary Materials for

## A wireless, solar-powered, optoelectronic system for spatial restriction-free long-term optogenetic neuromodulations

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**The PDF file includes:**

Figs. S1 to S18
Tables S1 to S3
Legends for movies S1 to S3

**Other Supplementary Material for this manuscript includes the following:**

Movies S1 to S3

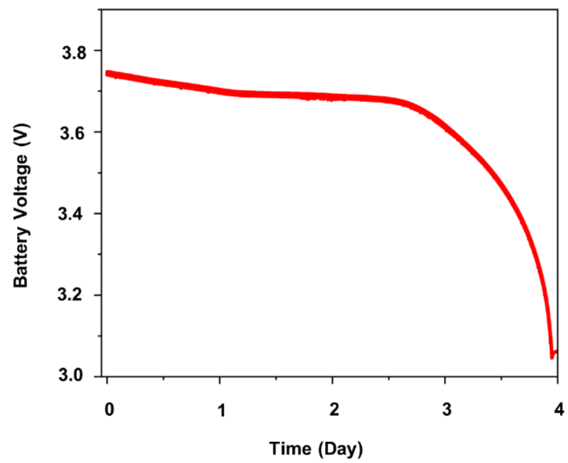


**Fig. S1.**

**The voltage change graph of LiPo battery without μ-led operation while maintaining Bluetooth signal.**

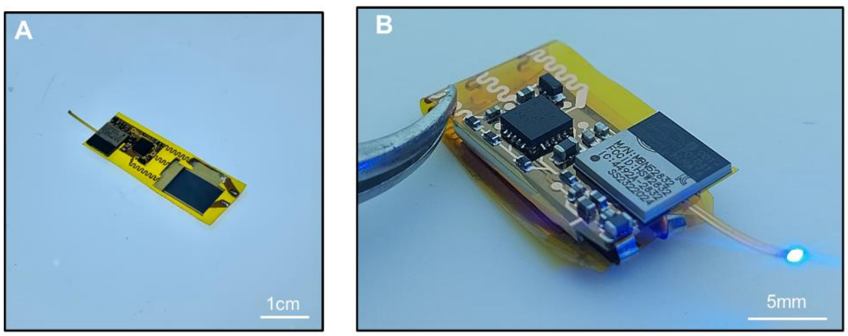


**Fig. S2.**

**Device Optical Image. (A)** Device optical image before folding. **(B)** Backside view of WSOD.

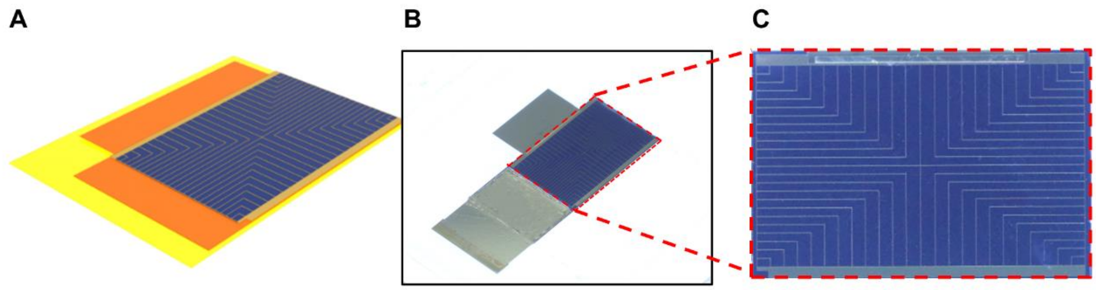


**Fig. S3.**

**Illustration and optical images of III-V PV device. (A)** Illustration of PV device. **(B)** Optical Image of PV device before WSOD integration. **(C)** Enlarged view of PV device.

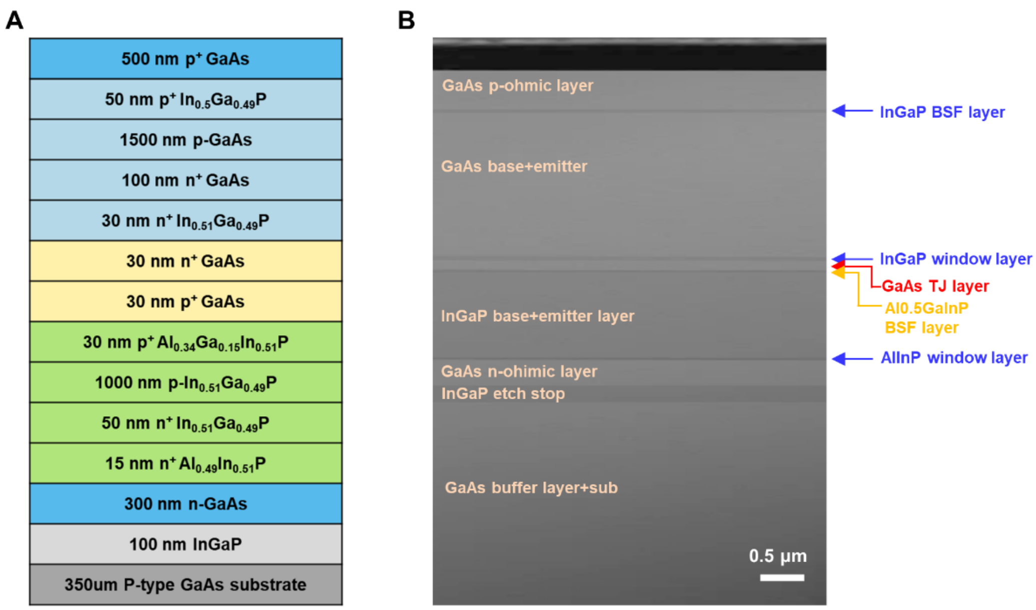


**Fig. S4.**

**High Efficiency, inverted dual junction InGaP/GaAs solar cell epitaxy structure. P-type GaAs substrate is removed for fabricating as a flexible form. (A)** Illustration of solar cell epitaxy structure. **(B)** Transmission electron microscopy image of PV device.

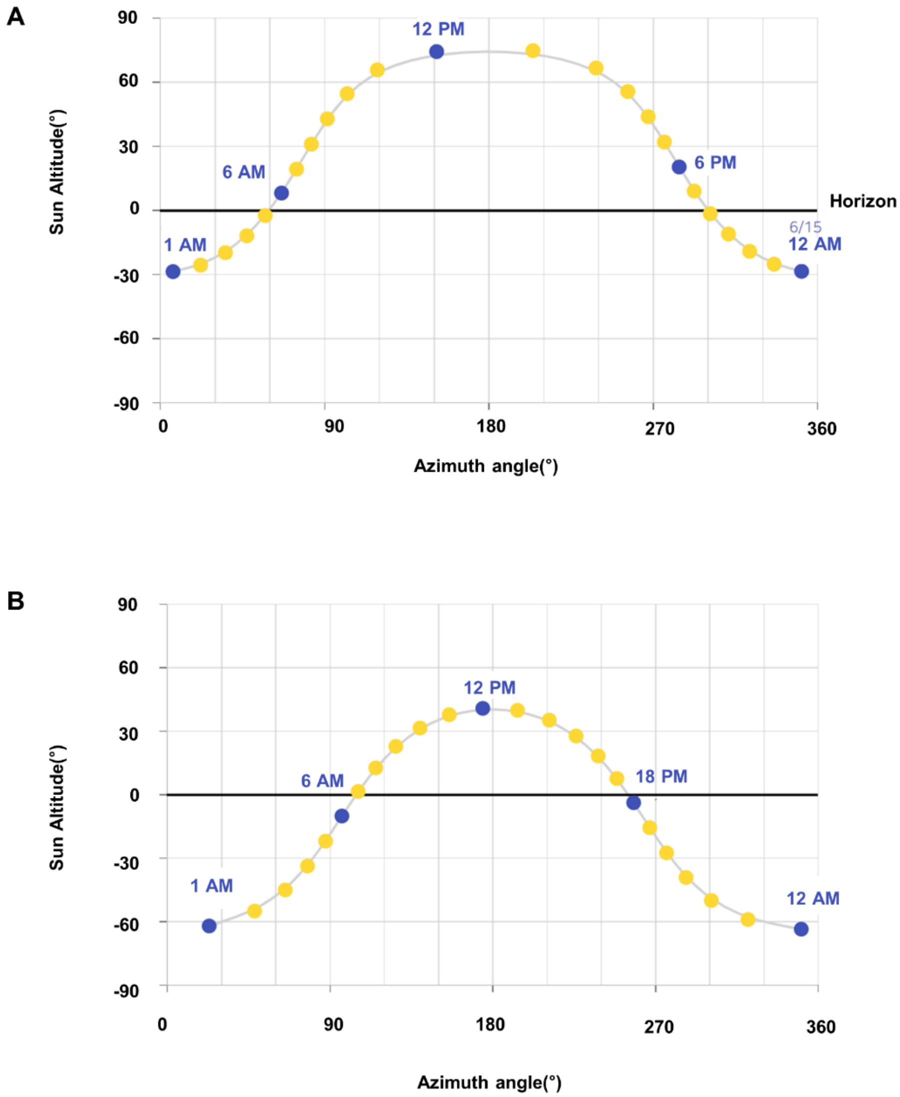


**Fig. S5.**
**The actual Azimuth angle and altitude angle of sun in summer(A) and autumn(B). (A)** is the information about the measured day of Fig. 2F and Fig. 2G. **(B)** is about Figure 2e.

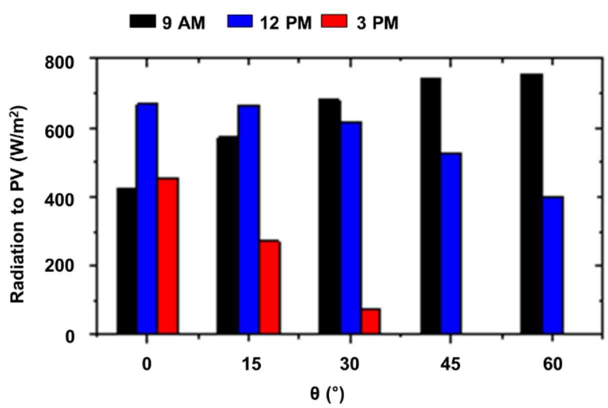


**Fig. S6.**

**Simulated radiation intensity reaching the PV of WSOD in accordance with the tilted position and time. Ground reflection and atmospheric scattering were not considered during the calculations.**

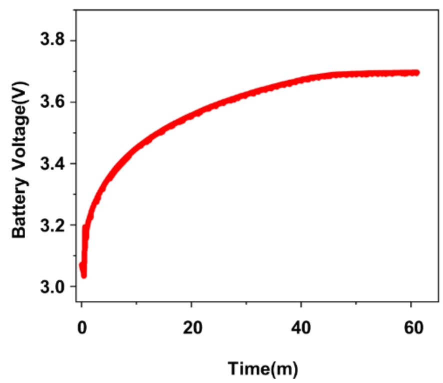


**Fig. S7.**

**Battery charging graph using LEDs lamp which can be used for indoor settings.**

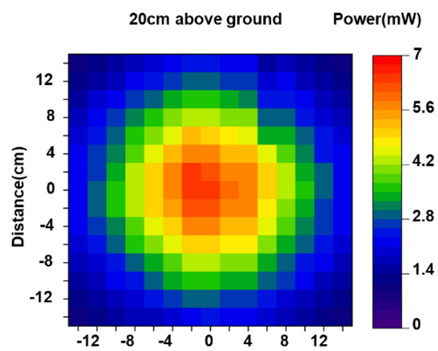


**Fig. S8.**

**2D colored plot of harvested energy measured by placing a lamp 20 cm above the WSOD.**

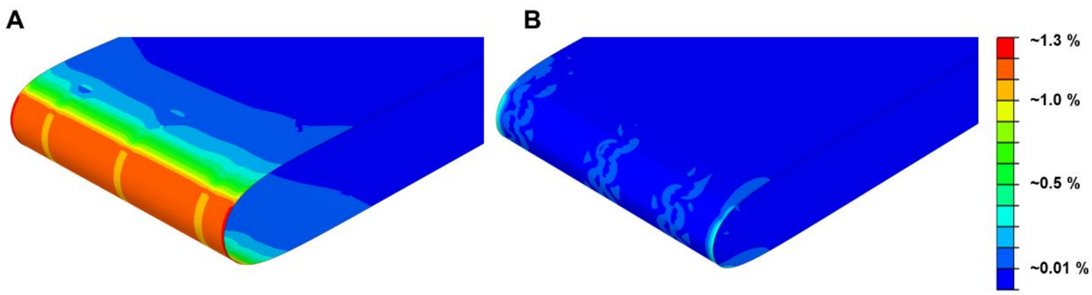


**Fig. S9.**

**FEM simulation results of WSOD with polyimide substrate in folded state. (A)** Folding area with straight line interconnects. **(B)** Folding area with serpentine line interconnects.

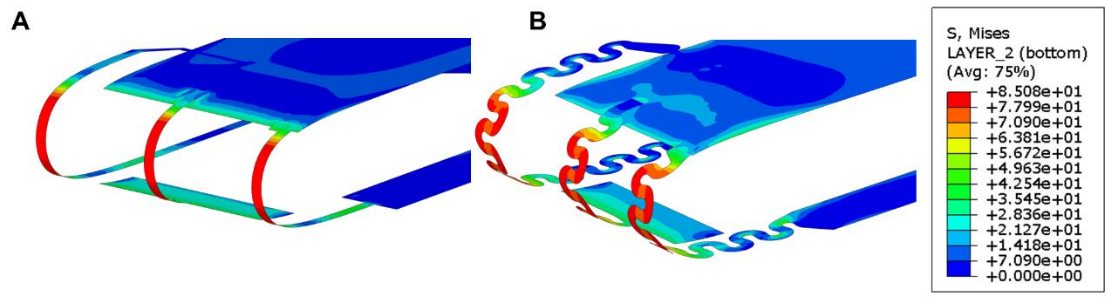


**Fig. S10.**

**FEM simulation of Von Mises Stress in folded state. (A)** Folding area with straight line interconnects. **(b)** Folding area with serpentine line interconnects.

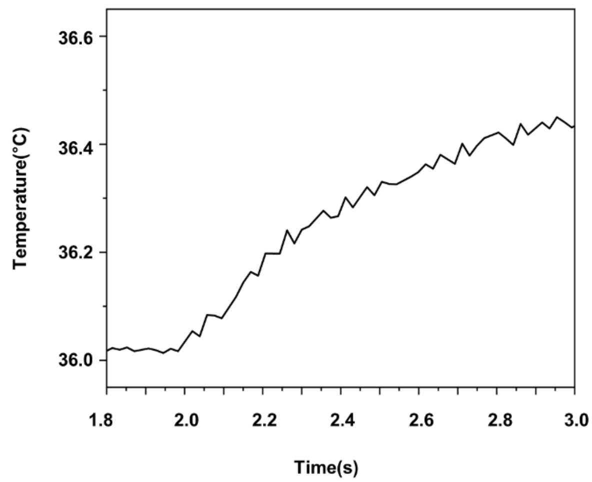


**Fig. S11.**

**The enlarged graph presenting the initial phase of temperature variation in the probe.**

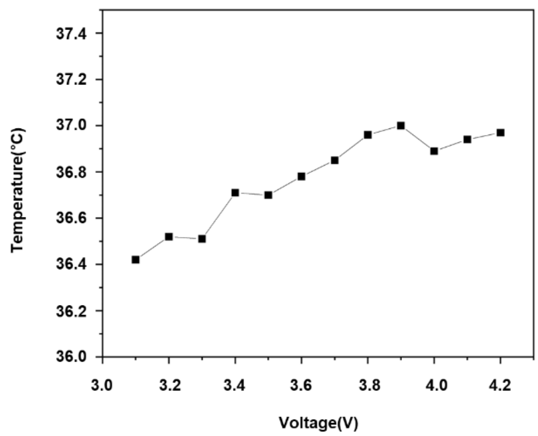


**Fig. S12.**

**Maximum temperature of µ-led according to battery voltage level satisfying the ISO standard even at the maximum variation (< 0.6 °C).**

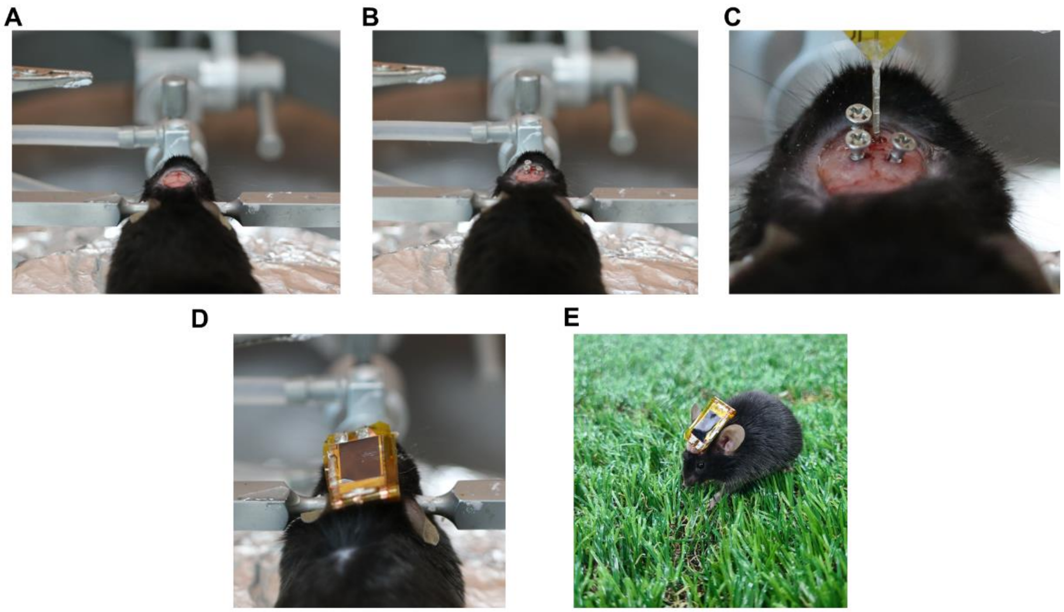


**Fig. S13.**

**Photos of device implant process for wireless solar-powered optoelectronics**. **(A)** Incision for mouse head skin. **(B)** Drilling screws for device fixation. **(C)** μ-led probe implantation after PEG coating. **(D)** Device probe bending after implant. **(E)** Freely behaving mice with the implanted device.

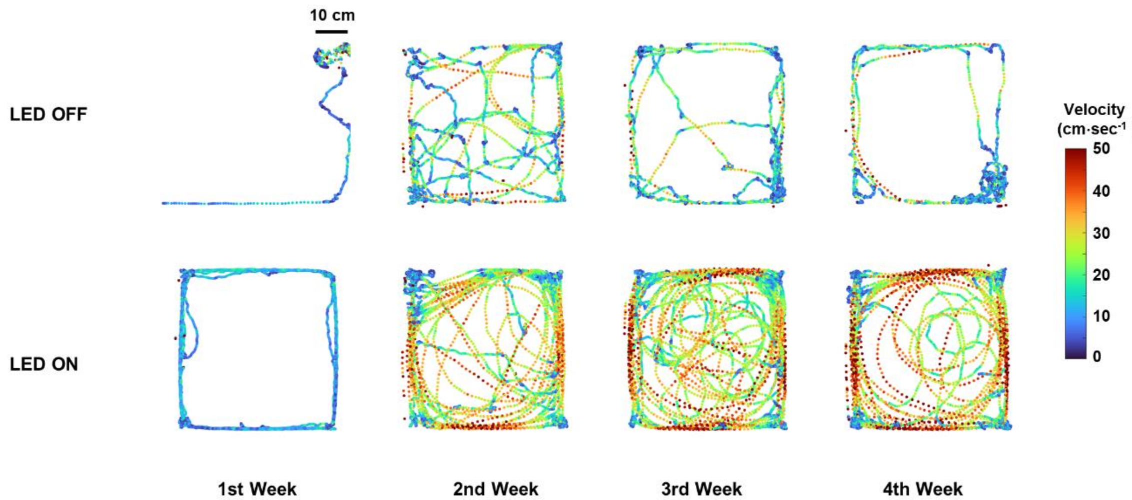


**Fig. S14.**

**Velocity tracking maps of the behavioral in vivo experiments conducted several times over the course of a month.**

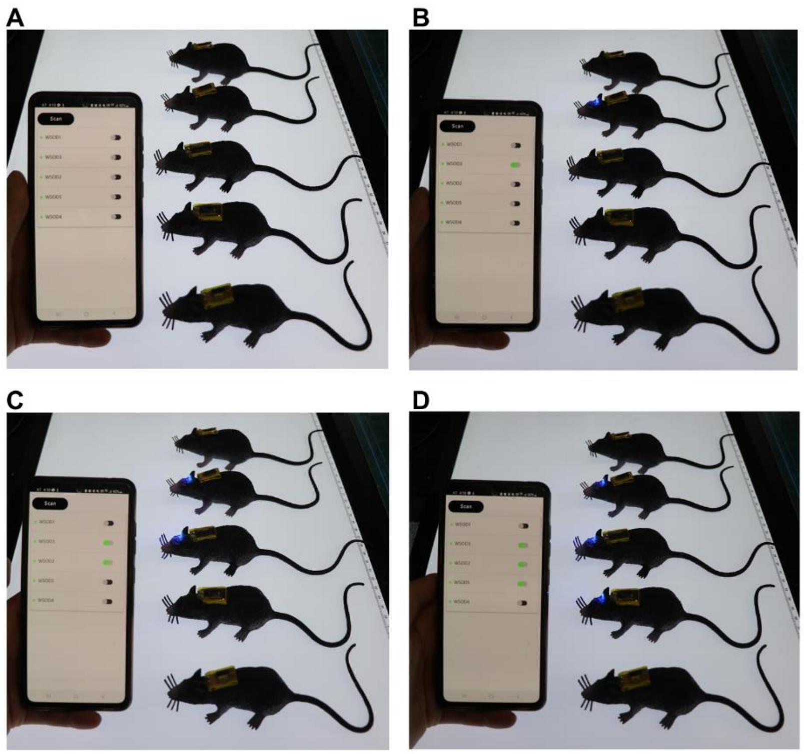

**Fig. S15.**

**Multi-connection Operation with 5 WSOD.** Connecting devices and turning on leds in sequence for the user's desired target **(A - D).**

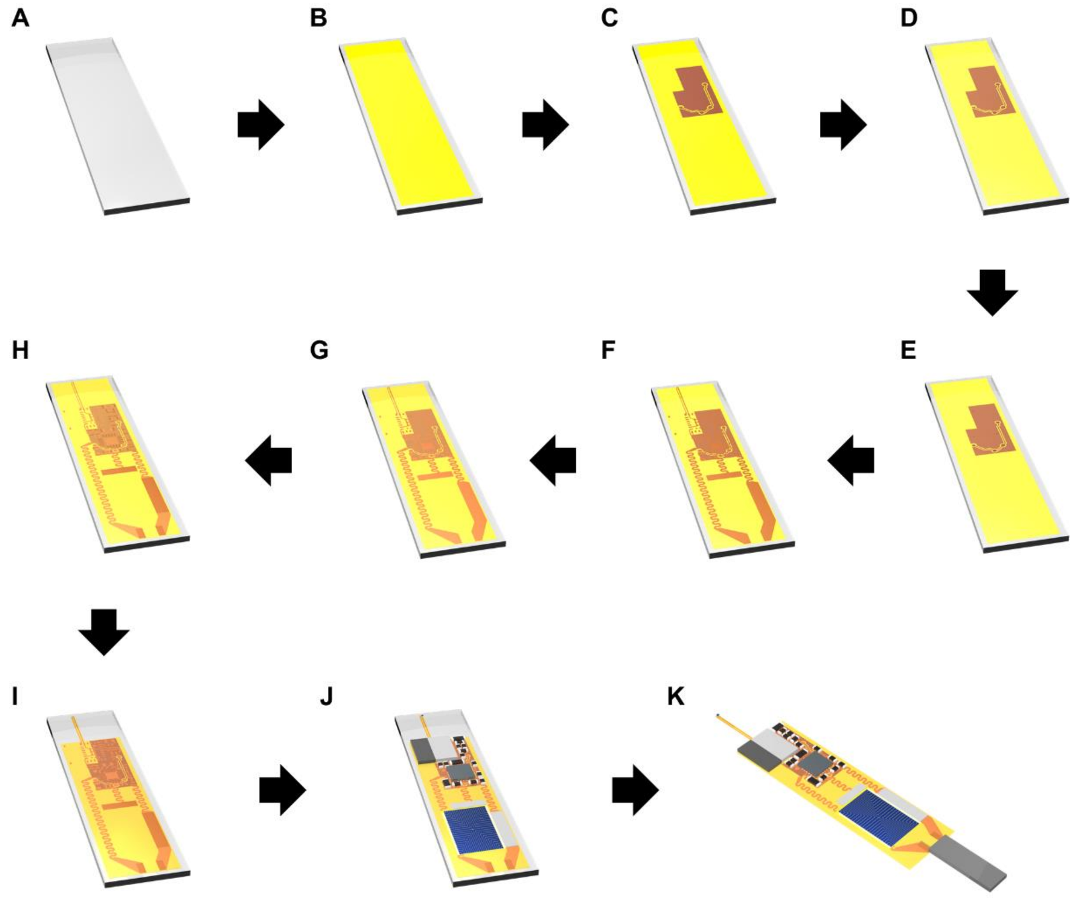


**Fig. S16.**

**Fabrication process of wireless solar-powered optogenetic device. (A**) Preparing glass substrate with PDMS coating. **(B)** Laminate polyimide film. **(C)** Copper deposit and patterning for the bottom layer. **(D)** Coating second polyimide layer for insulating. **(E)** Via etching for connecting the bottom layer and top layer. **(F)** Copper deposit and patterning for the top layer. **(G)** Coating outer layer for interconnect line protection. **(H)** Expose pad. **(I)** Device cutting. **(J)** Chip soldering and solar cell integration. **(K)** Battery integration and detaching device from a glass substrate.

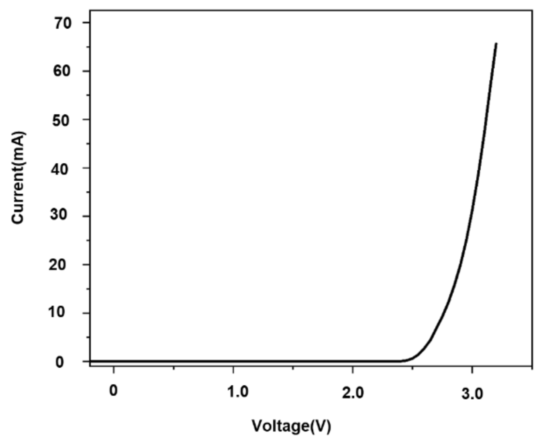


**Fig. S17.**

**I-V curve of commercial μ-led**

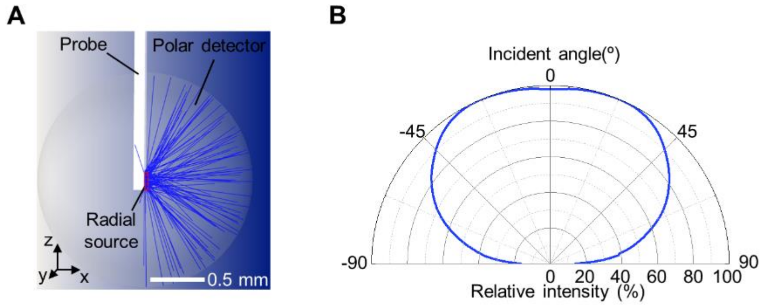


**Fig. S18.**

**Angular intensity of light source in the simulation. (A)** Scheme of the ray-tracing simulation result with radial light source (465 nm). **(B)** Calculated angular intensity of the radial light source.

**Table S1.**

**Comparison of state-of-the-art wireless brain optogenetic device**

| Wireless Brain Optogenetics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Fully implantable device with photovoltaics with NIR | Miniaturized photovoltaci and rf powered system | Stretchable multichannel antennas | Multilateral devices for optogenetic studies of individual | Subdermal implant for wireless charging and control | Optofluidic brain probes for chronic neuropharmacology | This Work |
| Power Source | Photovoltaic | Photovoltaic/RF | RF | RF | RF/Battery | Battery | Photovoltaic/ Battery |
| Not Tethered | X (Anesthetized) | O | O | O | O | O | O |
| Unnecessity of Bulky Equipment | O | X | X | X | X | O | O |
| Smarphone Applications | X | X | X | X | O | O | O |
| Long-term *in vivo* experiment | X | - | - | - | - | O (4week) | O (4week) |
| Fully Spatial Restriction-Free(Charging & Operating) | X | X | X | X | X | ▲(Requiring battery replacement) | O |
| Reference | *25* | *24* | *21* | *22* | *32* | *10* | |

**Table S2.**

**Voltage, current, and harvested power from various light sources with different environments**

| Harvested Power per Various Light Source | | | | |
|---|---|---|---|---|
| | **Height/Time** | **Voltage(V)** | **Current(mA)** | **Power(mW)** |
| **Searchlight** | 3 cm | 1.9 | 10 | 19 |
| **LAMP** | 20 cm | 1.947 | 3.57 | 6.95 |
| | 30 cm | 1.784 | 1.55 | 2.76 |
| | 40 cm | 1.750 | 0.89 | 1.55 |
| **Sunlight** | 12 PM (Summer) | 1.80 | 6.84 | 15.39 |
| | 9 AM (Autumn) | 1.78 | 3.46 | 6.16 |
| | 12 PM (Autumn) | 1.8 | 5.6 | 10.08 |
| | 3 PM (Autumn) | 1.77 | 3.33 | 5.89 |
| **Shade** | 12 PM | 1.73 | 1.1 | 1.90 |
| **Bulb** | 5 cm | 1.73 | 0.5 | 0.86 |

**Table S3.**

**Information for the parameters of mouse brain. Optical coefficients of the mouse brain used in the optical simulations.**

| Mouse brain | |
|---|---|
| Wavelength | 460 nm |
| g | 0.3 |
| $\mu_s$ ($mm^{-1}$) | 3.8 |
| $\mu_a$ ($mm^{-1}$) | 1.0 |
| Refractive index | 1.36 |

**Movie S1. (separate file)**
**Charging WSOD with searchlight and operating μ-led via Bluetooth.**

**Movie S2. (separate file)**
**Locomotion behavior with 3min intervals for 15 minutes. (Off-On-Off-On-Off)**

**Movie S3. (separate file)**
**Multi-connection with a single mobile interface**