COMSOL Multiphysics® Based Simulation of Optical Response in Si Micro-line Array based Broadband Photodetector Fabricated on Silicon-on-insulator (SOI) Wafers

V. K. Aggarwal[1], S. Sett[1], A. Singha[2] & A. K. Raychaudhuri[1]
[1] S. N. Bose National Centre For Basic Sciences, Kolkata 700098, India.
[2] Bose Institute, Kolkata 700009, India.

COMSOL CONFERENCE
2019 BANGALORE

INTRODUCTION

- Commercially available photodetectors (Si/Ge) have Responsivity (R) < 0.6A/W

- In semiconductor nanowires like Si/ZnO/Ge it has been observed that R is in the range of 10^2-10^7 A/W

- Fabrication of photodetectors using nanowires is a complex process and in particular, it is not possible to have high production rate needed for commercial purpose in fabrication of devices made from single nanowires grown ex-situ bottom-up process.

HIGHLIGHTS

- We made an array of Si microlines (~1 µm wide) fabricated by a top-down process that is compatible with wafer level processing.

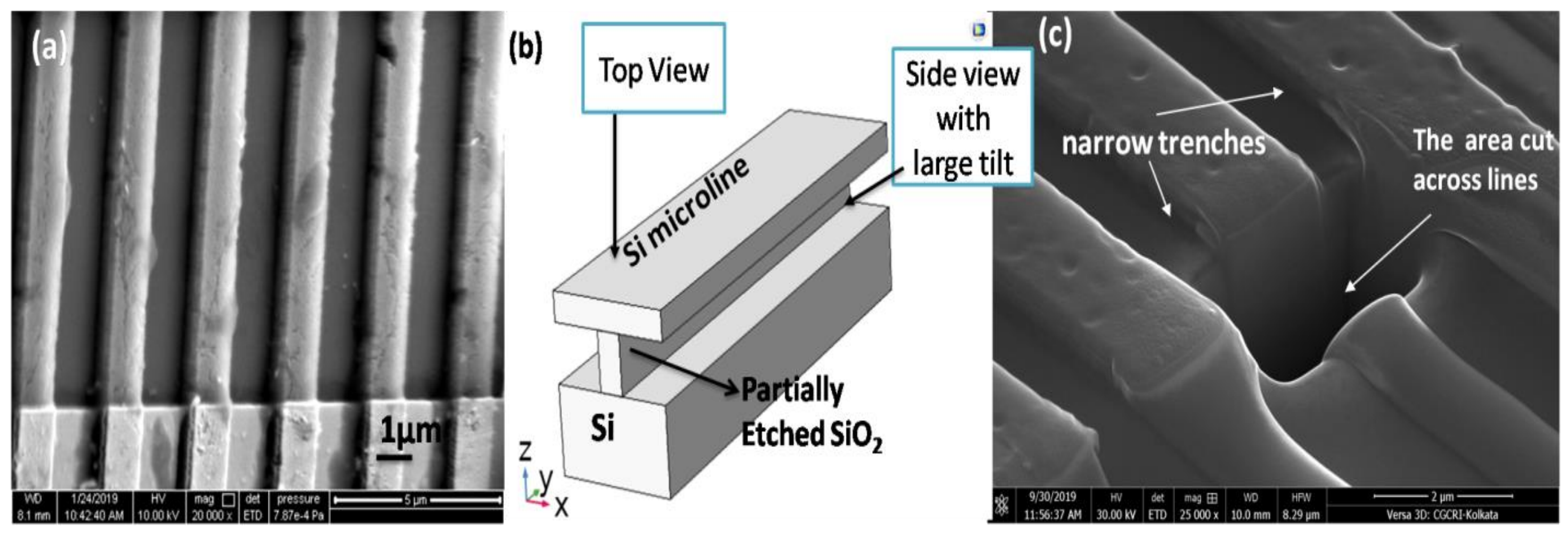

Figure 1. (a) FESEM image of array of Si microlines. (b) Schematic of the partially suspended device created by etching. (c) Magnified view showing partially suspended Si microlines.

- Make Metal-semiconductor-metal (MSM) photodetectors from the Si microlines.

- Achieve a large responsivity (R) larger than that available in commercial p-n detectors (0.6 A/W) although less than that in a single Si NW device (10^4 A/W).

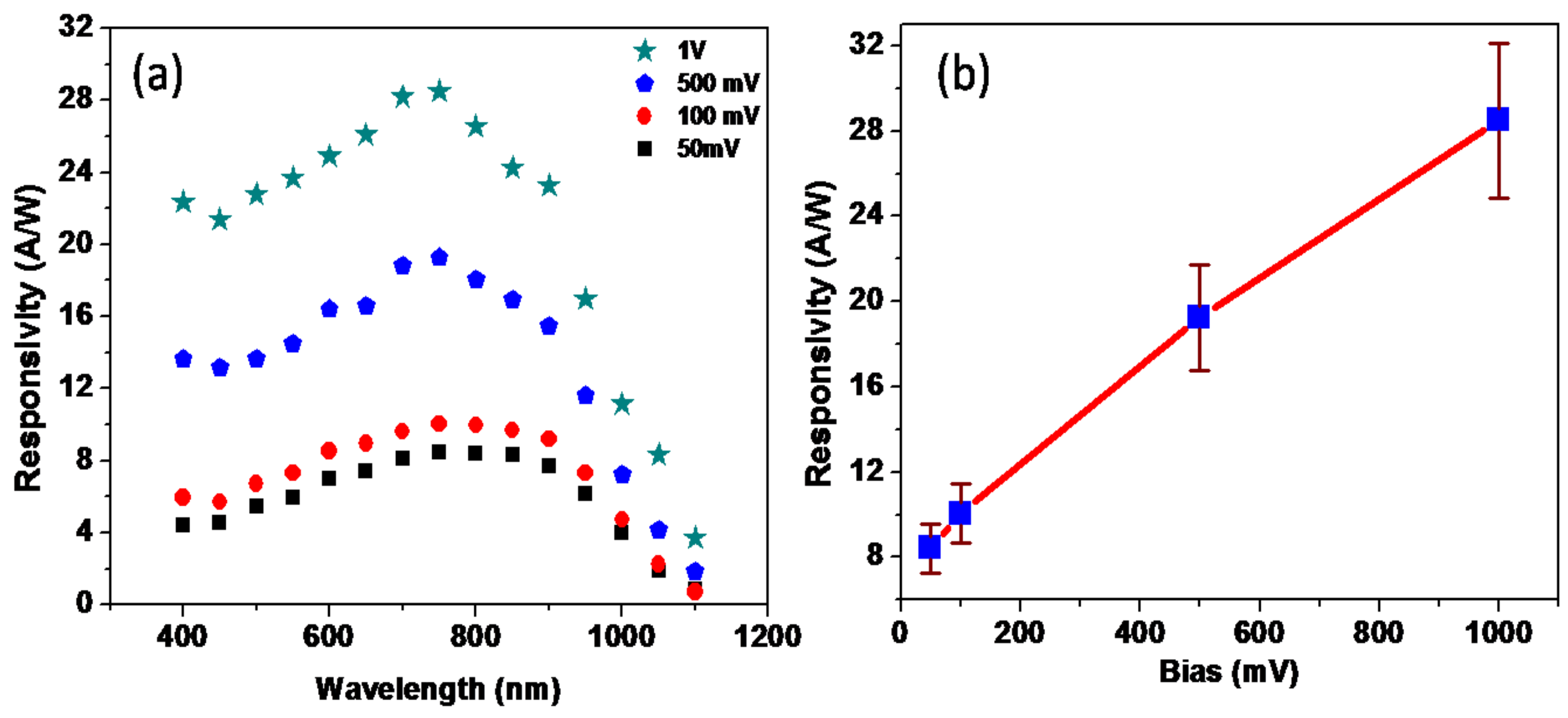

Figure 2. (a) Responsivity as a function of wavelength at different values of applied bias. (b) Peak responsivity (λ=750 nm) as function of applied bias with intensity varying from 5 - 7 W/m^2.

COMPUTATIONAL METHOD

High responsivity from Si microline array as observed is due to its partial suspension which has been validated by the simulation using the semiconductor module coupled with AC/DC module using a frequency domain study.

$$J_n(r,t) = qn\mu_n\nabla\varphi_c + \mu_n k_B T K\left(\frac{n}{N_c}\right)\nabla n + \left(\frac{nq}{T}\right)D_{n,th}\nabla T$$

$$J_p(r,t) = qp\mu_p\nabla\varphi_v + \mu_p k_B T K\left(\frac{p}{N_v}\right)\nabla p - \left(\frac{pq}{T}\right)D_{p,th}\nabla T$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\left(\nabla . J_n\right) - U_n \quad \text{and} \quad \frac{\partial p}{\partial t} = \frac{-1}{q}\left(\nabla . J_p\right) - U_p$$

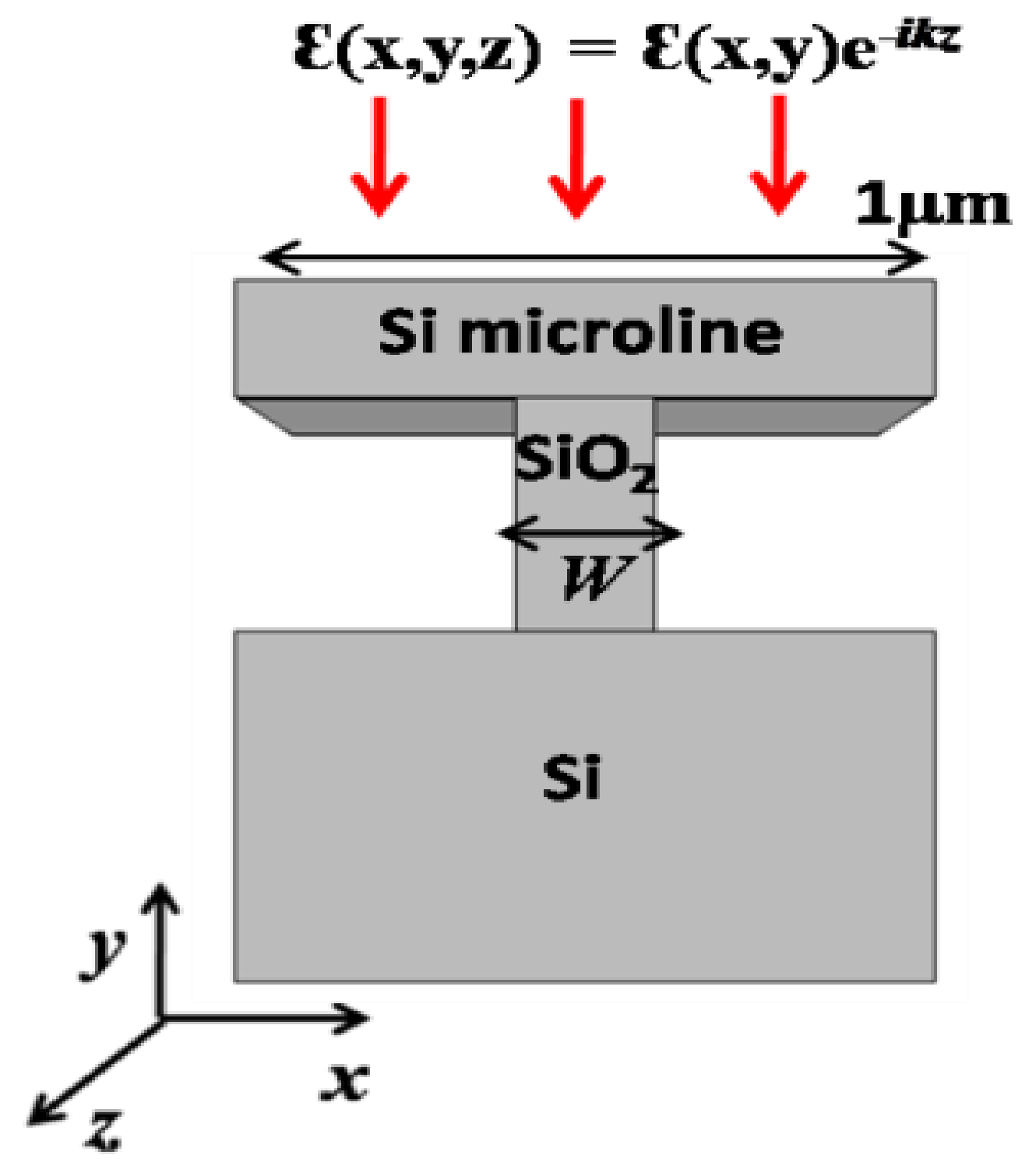

Figure 3. Cross-sectional image of device geometry of partially suspended Si microline used for simulation. The width *W* of the SiO$_2$ under-layer is a variable parameter in the simulation

RESULTS

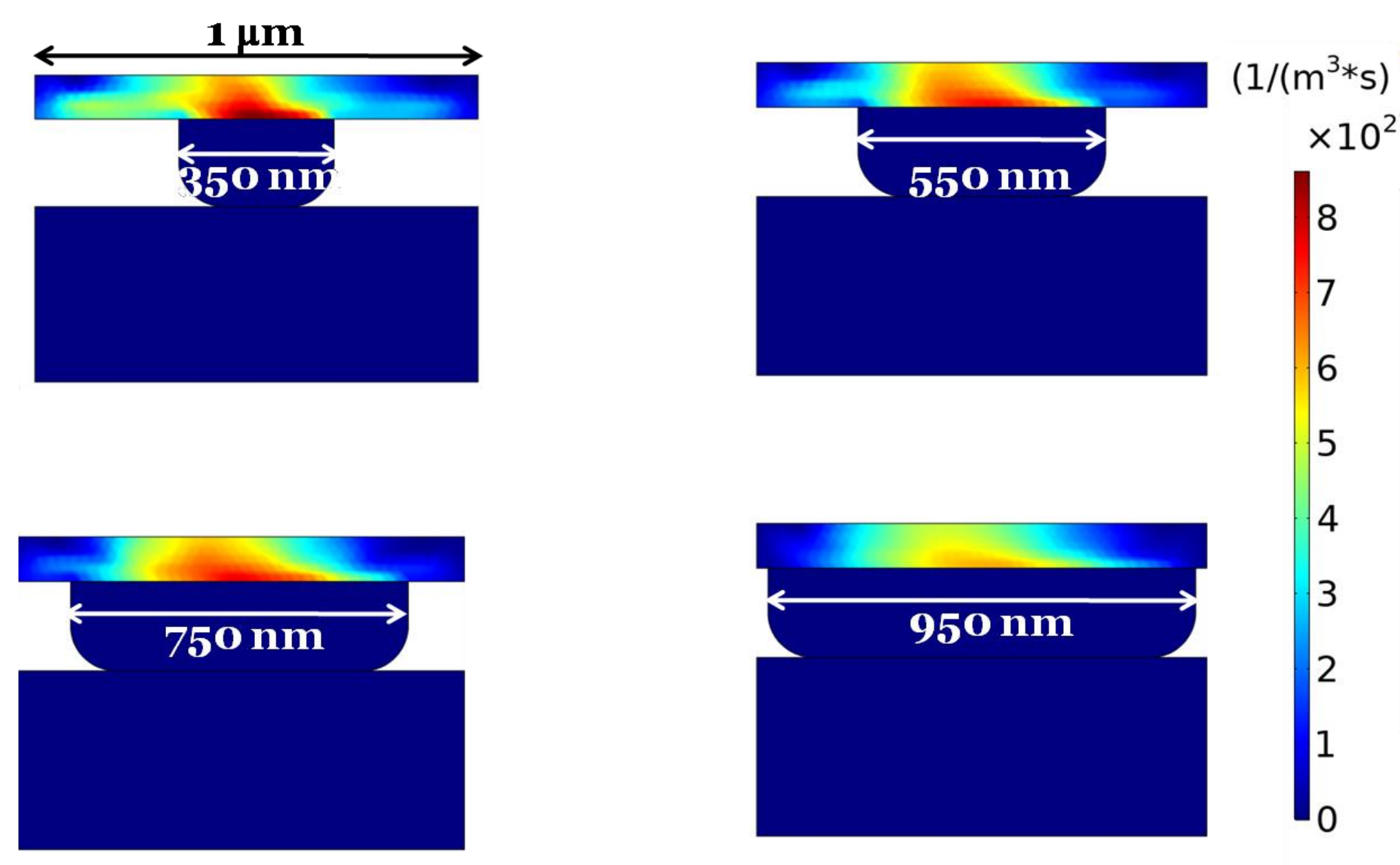

Figure 4. Surface plot of the carrier Recombination rate per unit volume in partially suspended Si microline with different W. Color legend is given alongside

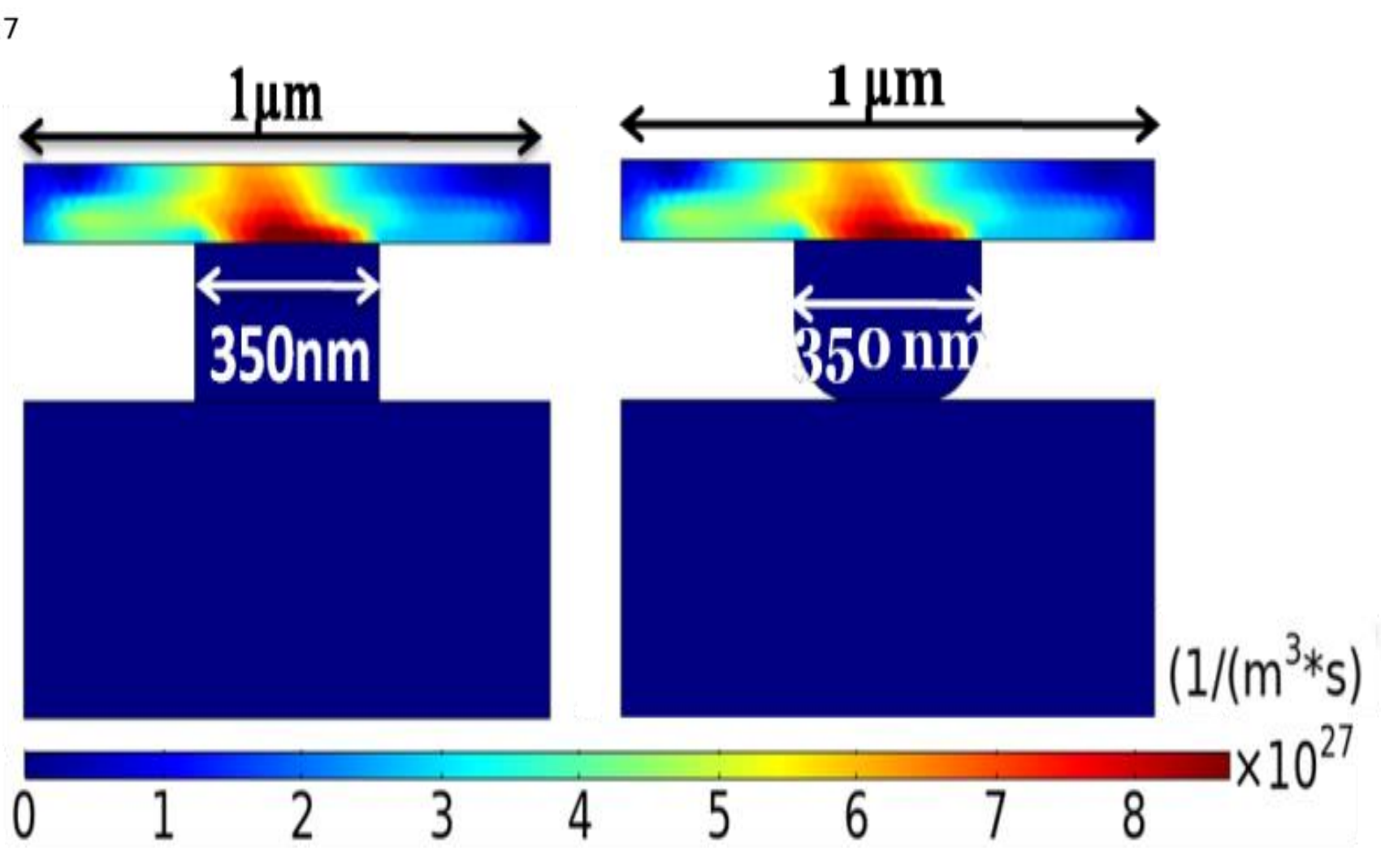

Figure 5. Surface plot of carrier Recombination rate per unit volume in partially suspended Si microline with *W*=350 nm (a) sharp anisotropic etch profile (b) lateral etch profile. Color legend is given below

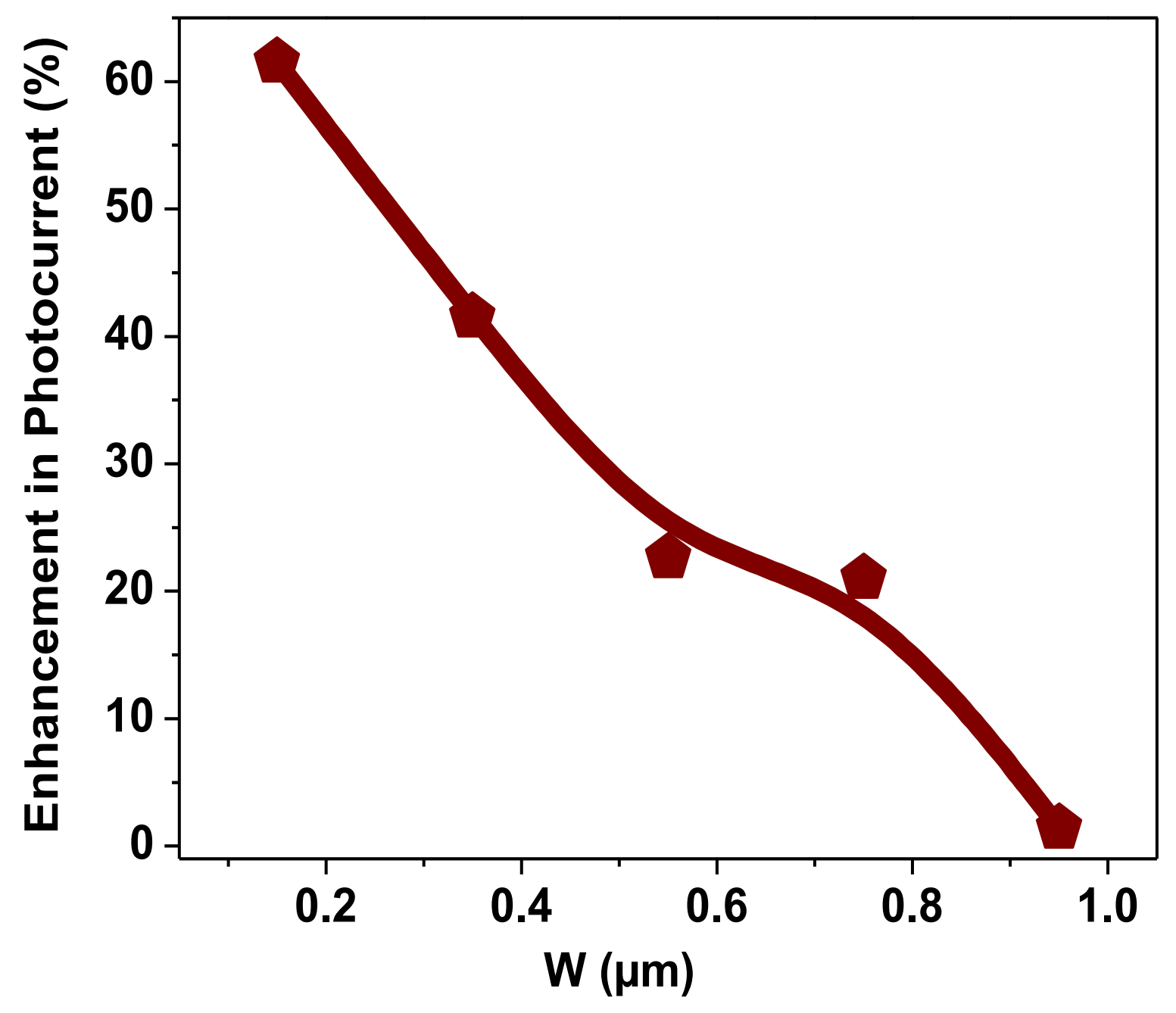

Figure 6. Dependence of the enhancement of photocurrent (over dark current)

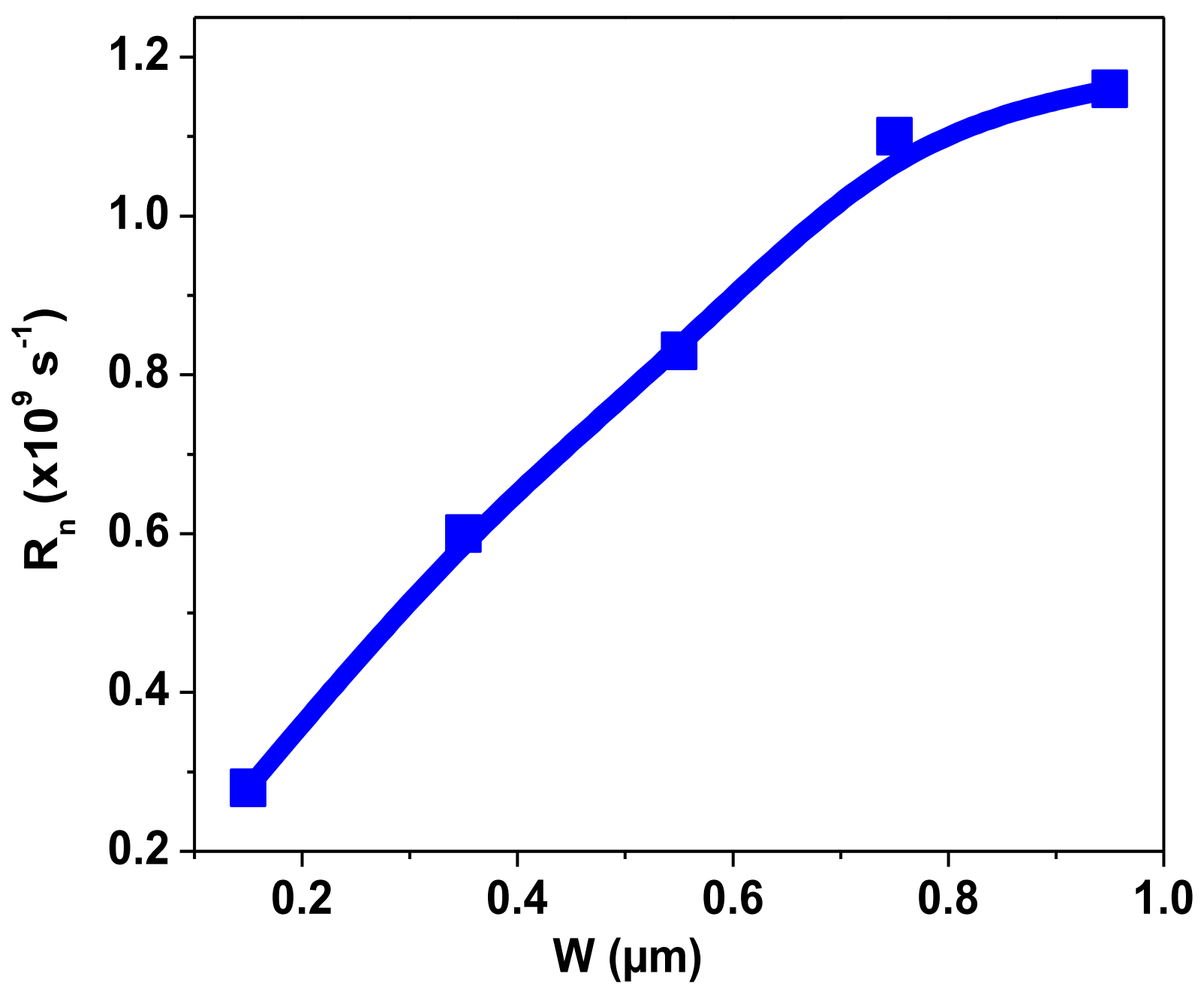

Figure 7. carrier recombination rate R$_n$ on the width W of the underlying SiO$_2$ layer that supports the microline

CONCLUSIONS

❖ The Responsivity is at least an order higher than commercially available bulk Si detectors in the same spectral range.

❖ Si microlines, which are partially suspended, prevent recombination of carriers during transit, thereby elongating its lifetime and has been validated by using COMSOL Multiphysics® simulation.

REFERENCES

1. P. Duy Tran, J. Thomas Macdonald, B. Wolfrum, R. Stockmann, T. Nann, A. Offenhausser, and B. Thierry, Appl. Phys. Lett., 105, 231116 (2014)
2. L. Pescini, A. Tilke, R. H. Blick, H. Lorenz, J. P. Kotthaus, W. Eberhardt and D. Kern, Nanotech., 10, 418-420 (1999)