Image charge effect modulate carriers distribution in SiGe quantum wells

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Abstract Currently, it is understood that the carrier recombination rate in semiconductors can be modified by metals due to pure electrodynamic interactions through surface plasmons. We propose here an electrostatic mechanism for carrier-metallic nanoparticle interaction comparable in effect to plasmonic interactions. Arising from Coulomb attraction of electrons and holes to their images in metal, this mechanism produces large carrier concentrations near metallic nanoparticles. Increased concentration results in increased quantum efficiency and enhances the photoluminescence of the SiGe coaxial quantum wells.

Motivation

Metal nanoparticles possess superior capability to enhance emission of semiconductor quantum wells (QWs), quantum dots (QDs). Due to the strong electromagnetic wave generated by localized surface plasmon (LSP), a large electron-hole generation as well as recombination rate could be achieved, and thus the emission intensity of semiconductor can be greatly enhanced. However, carriers in QWs interact with the nanoparticles not only through LSP fields but also through Coulomb force. The universal image charge effect is not restricted by the frequency matching condition. In this work, we propose the use of nanoparticles as an effective method for modulation the carriers distribution. Image charge effect is a new way to increase light emission in Si-based system.

Result

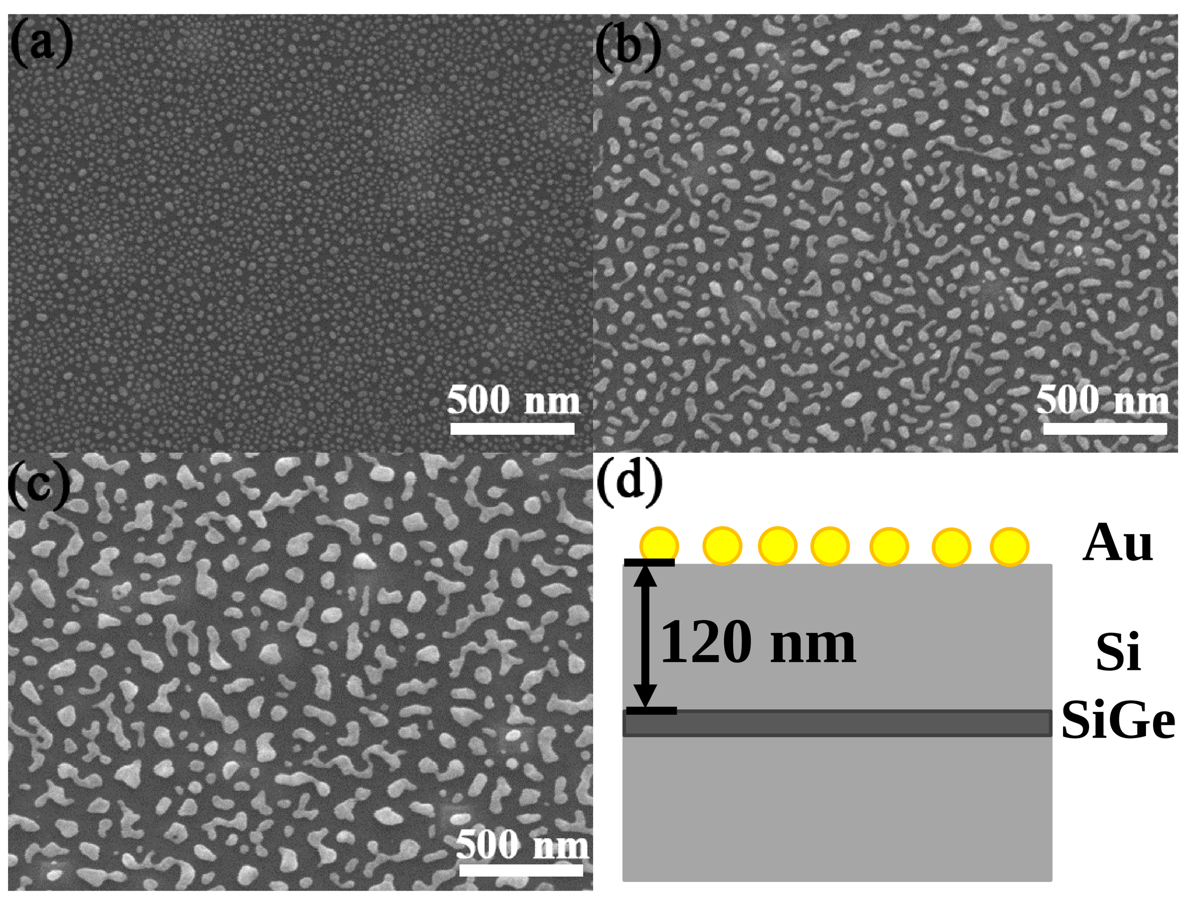

Fig. 1 Scanning electron microscope (SEM) image of Au nanoparticles, with average diameter of (a) 20 nm, (b) 35 nm, (c) 75 nm. (d) Structure of the SiGe quantum wells with Au nanoparticles.

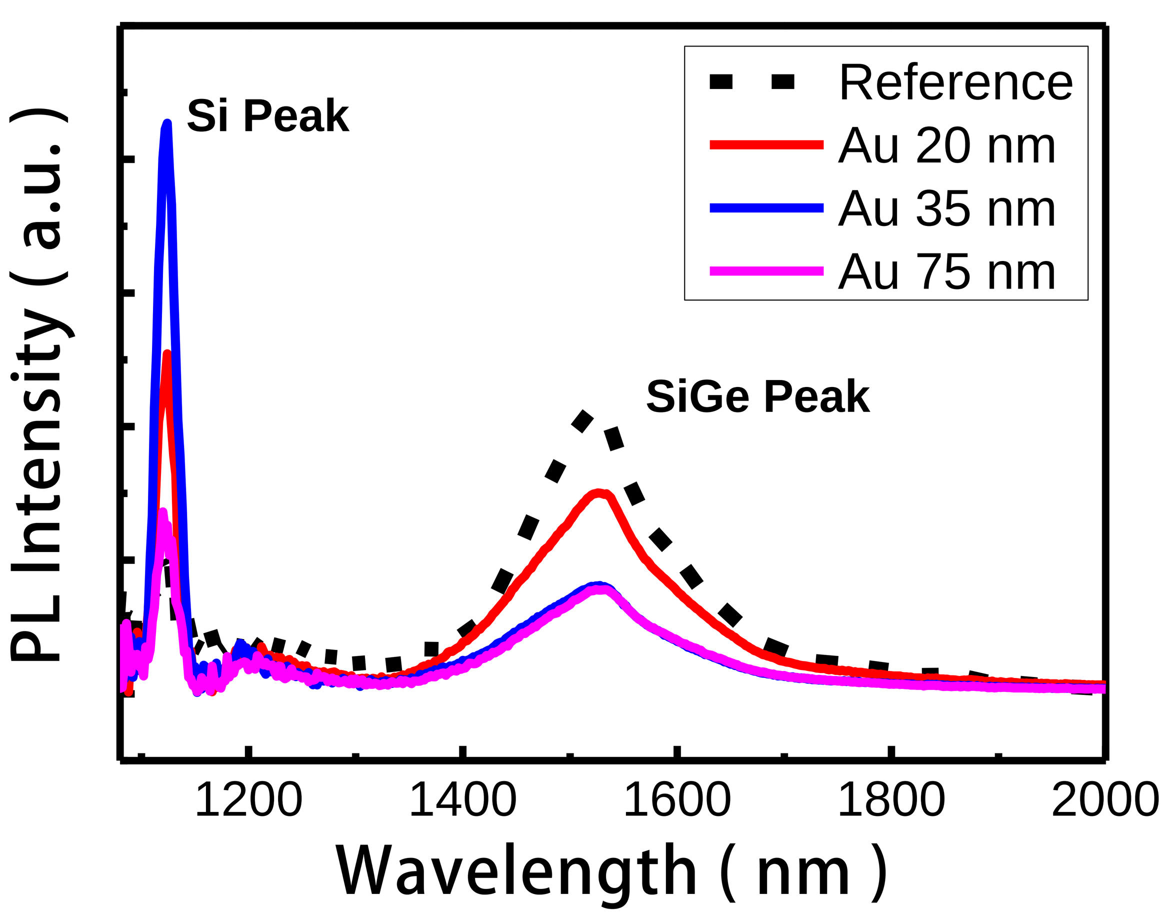

Fig. 2 PL spectra of SiGe quantum wells (QWs) with (solid line) and without (dashed line) Au nanoparticles.

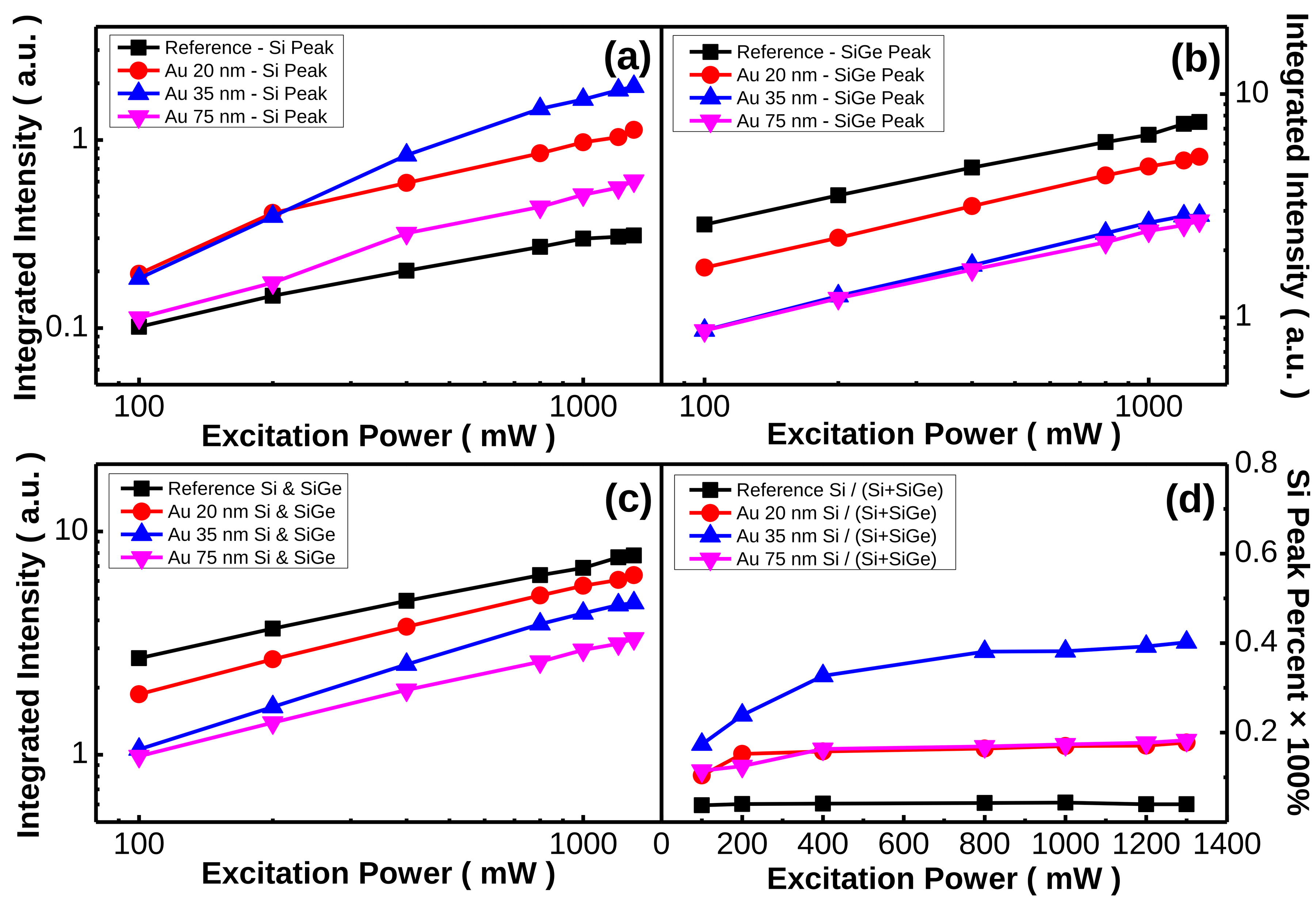

Fig. 3 (a) Si peak, (b) SiGe peak, (c) Si peak and SiGe peak integrated PL intensity as a function of the excitation power. (d) The Si peak intensity factor of $I_{Si}/(I_{Si} + I_{SiGe})$ as a function of the excitation power. I_{Si} denote the integrated PL intensity of Si peak, I_{SiGe} denote the integrated PL intensity of SiGe peak.

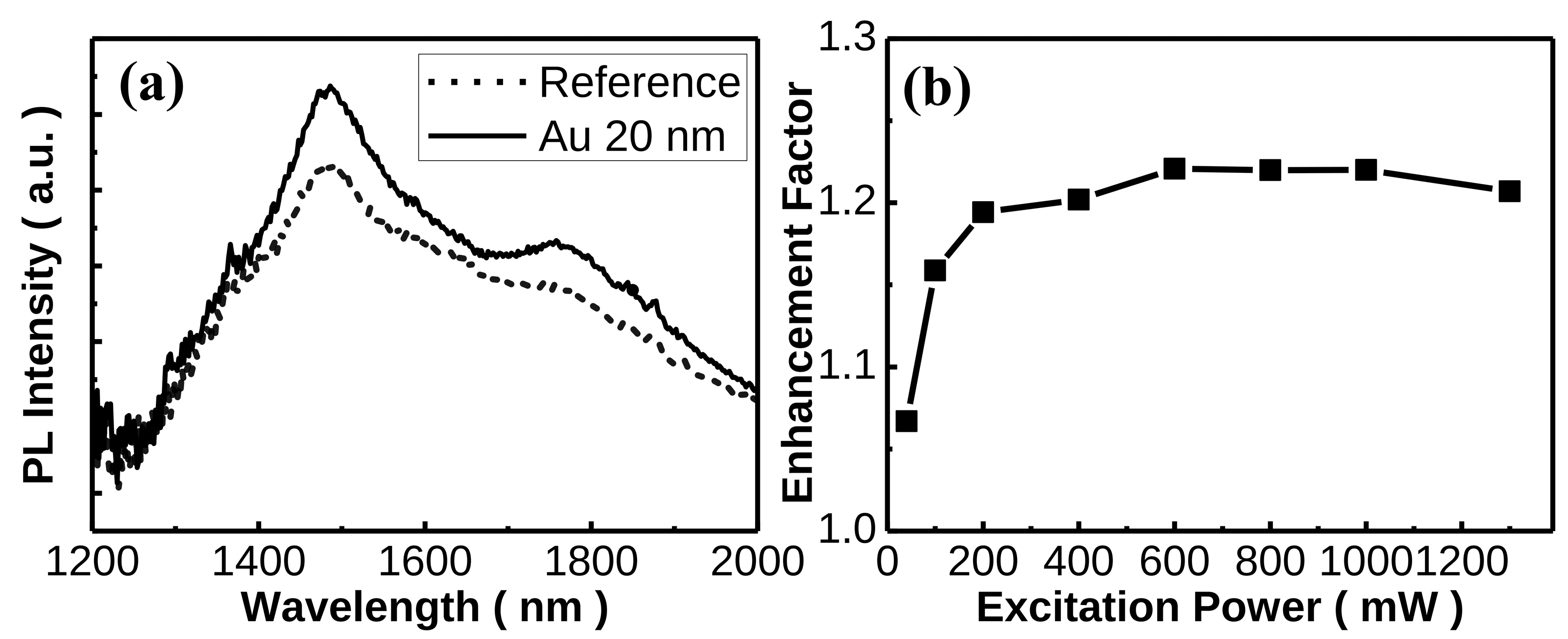

Fig. 4 (a) PL spectra of SiGe coaxial quantum wells (CQWs) on Si nanopillars with (solid line) and without (dashed line) 20 nm Au nanoparticles. (b) The enhancement factor of $I_{Au\text{-}CQW} / I_{CQW}$ versus the excitation power. $I_{Au\text{-}CQW}$ and I_{CQW} denote the integrated intensities of the PL from the SiGe CQWs with and without 20 nm Au nanoparticles, respectively.

Conclusion

The results here clearly illustrate the image charge effect modulate the carrier distribution. Neutral metal nanoparticles attract electrons and holes, causing the carriers to drift towards, and concentrate near, the nanoparticles, resulting in highly localized light emission. The image charge effect provides a nonresonant means for enhancing optical emission in Si-based systems.