Supporting Information

Enhancement of Terahertz Pulse Emission by Optical Nanoantenna

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Asymmetric scattering depending on the nanoantenna widths

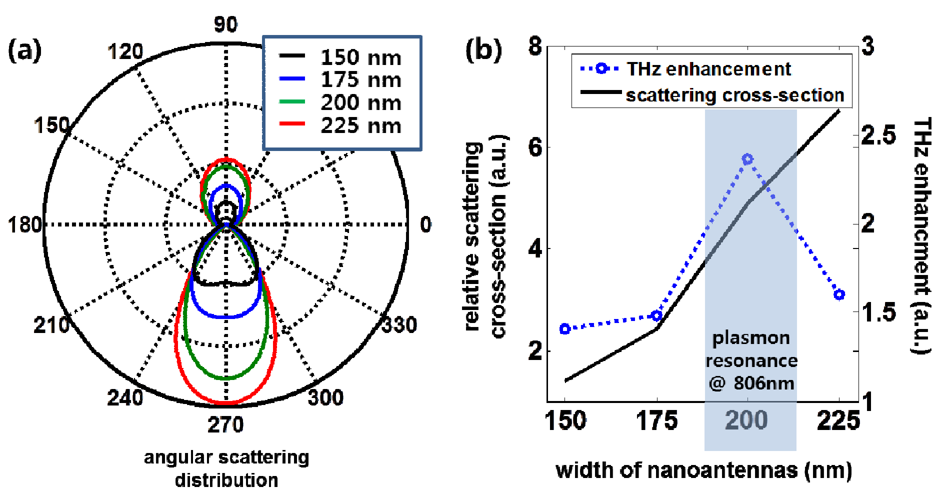

Figure S1. (a) Scattering distribution of optical nanoantennas on the SI-GaAs with different widths and (b) relative scattering cross-section with THz enhancement. The scattering cross-section increases with the nanoantenna width.

Bias electric field distribution. The bias electric field distribution was calculated by using the finite element analysis software, COMSOL Muliphysics (COMSOL 3.5, COMSOL Corp., Burlington, MA).

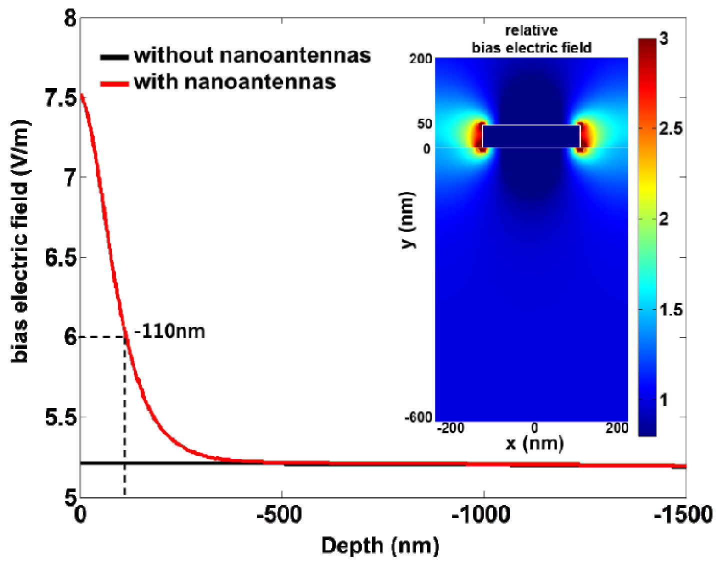

Figure S2. The bias electric field in the middle of the photoconductive region for with and without 200 nm wide nanoantennas as a function of a substrate depth (y-axis) and (subfigure) the distribution of relative bias electric field in the cross-section of optical nanoantennas.

Calculation of photocurrent. The amplitude of electric field of THz wave emitted from PCAs is related with the surface current. The THz wave generated from the PCA is proportional to the first-order time derivative of the surface current,

$$E(t) \propto \frac{\partial J_s(t)}{\partial t}$$

$$J_s(t) = \int_0^{\delta} J(z,t)dz$$

where $J_s(t)$ is the surface current, $J(z,t)$ is the current density and δ is the distance into the photoconductor.

In general, current density is determined by multiply of the number of carrier and the bias electric field, as shown the follow equation,

$$\mathbf{J}(\mathbf{r},t) = q\, n(\mathbf{r},t)v_d(r,t) = q\, n(\mathbf{r},t) * \mu E_b(r,t)$$

where $n(\mathbf{r},t)$ is the carrier density, $v_d(r,t)$ is draft velocity, μ is the electron mobility and $E_b(r,t)$ is the bias electric field. And the carrier density can be calculated from the energy density absorbed in a photoconductive substrate, $\frac{imag(\epsilon)|E|^2}{2}$. Therefore increase of photocurrent can be obtained from the optical electric field and the bias electric field. Calculated based on above equation, photocurrent is increased by 2 times in the photoconductive layer, which corresponding to 4 times THz enhancement factor. The thickness of photoconductive layer is assumed to be 110 nm where the bias electric field has fallen to 1/e (about 0.37) of its peak value.

Saturation of THz emission power. The experiment of the saturation of THz emission was carried out with increasing pump beam power.

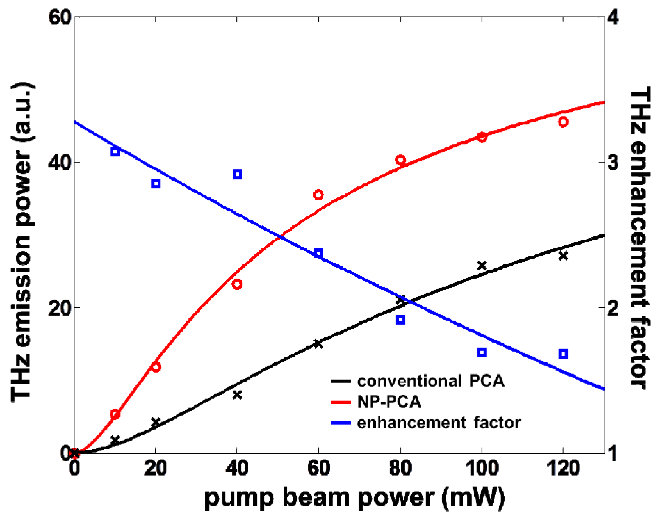

Figure S3. THz emission power from the NP-PCA integrating 200 nm wide nanoantennas and the conventional PCA, and THz enhancement factor depending on optical pump beam power. The THz emission from NP-PCA is saturated around 80 mW.