Terahertz photoconductive antenna with metal nanoislands

Sang-Gil Park,[1,2,3] Yongje Choi,[1,3] Young-Jae Oh,[1] and Ki-Hun Jeong[1,2,*]

[1]*Department of Bio and Brain Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, South Korea*

[2]*KAIST Institute for Optical Science and Technology, Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, South Korea*

[3]*These authors contributed equally to this work*

[*]*kjeong@kaist.ac.kr*

Abstract: This work presents a nanoplasmonic photoconductive antenna (PCA) with metal nanoislands for enhancing terahertz (THz) pulse emission. The whole photoconductive area was fully covered with metal nanoislands by using thermal dewetting of thin metal film at relatively low temperature. The metal nanoislands serve as plasmonic nanoantennas to locally enhance the electric field of an ultrashort pulsed pump beam for higher photocarrier generation. The plasmon resonance of metal nanoislands was achieved at an excitation laser wavelength by changing the initial thickness of metal film. This nanoplasmonic PCA shows two times higher enhancement for THz pulse emission power than a conventional PCA. This work opens up a new opportunity for plasmon enhanced large-aperture THz photoconductive antennas.

OCIS codes: (310.6628) Subwavelength structures, nanostructures; (110.6795) Terahertz imaging; (040.5150) Photoconductivity; (250.5403) Plasmonics.

References and links

1. M. Tonouchi, "Cutting-edge terahertz technology," Nat. Photonics **1**(2), 97–105 (2007).
2. E. Pickwell and V. P. Wallace, "Biomedical applications of terahertz technology," J. Phys. D Appl. Phys. **39**(17), R301–R310 (2006).
3. K. Kawase, Y. Ogawa, Y. Watanabe, and H. Inoue, "Non-destructive terahertz imaging of illicit drugs using spectral fingerprints," Opt. Express **11**(20), 2549–2554 (2003).
4. N. Nagai, R. Kumazawa, and R. Fukasawa, "Direct evidence of inter-molecular vibrations by THz spectroscopy," Chem. Phys. Lett. **413**(4-6), 495–500 (2005).
5. M. Exter, C. Fattinger, and D. Grischkowsky, "Terahertz time-domain spectroscopy of water vapor," Opt. Lett. **14**(20), 1128–1130 (1989).
6. R. M. Woodward, B. E. Cole, V. P. Wallace, R. J. Pye, D. D. Arnone, E. H. Linfield, and M. Pepper, "Terahertz pulse imaging in reflection geometry of human skin cancer and skin tissue," Phys. Med. Biol. **47**(21), 3853–3863 (2002).
7. M. Tani, S. Matsuura, K. Sakai, and S. Nakashima, "Emission characteristics of photoconductive antennas based on low-temperature-grown GaAs and semi-insulating GaAs," Appl. Opt. **36**(30), 7853–7859 (1997).
8. Y. C. Shen, P. C. Upadhya, E. H. Linfield, H. E. Beere, and A. G. Davies, "Ultrabroadband terahertz radiation from low-temperature-grown GaAs photoconductive emitters," Appl. Phys. Lett. **83**(15), 3117–3119 (2003).
9. A. Dreyhaupt, S. Winnerl, T. Dekorsy, and M. Helm, "High-intensity terahertz radiation from a microstructured large-area photoconductor," Appl. Phys. Lett. **86**(12), 121114 (2005).
10. B. Pradarutti, R. Müller, W. Freese, G. Matthäus, S. Riehemann, G. Notni, S. Nolte, and A. Tünnermann, "Terahertz line detection by a microlens array coupled photoconductive antenna array," Opt. Express **16**(22), 18443–18450 (2008).
11. S.-G. Park, K. H. Jin, M. Yi, J. C. Ye, J. Ahn, and K.-H. Jeong, "Enhancement of terahertz pulse emission by optical nanoantenna," ACS Nano **6**(3), 2026–2031 (2012).
12. C. W. Berry and M. Jarrahi, "Plasmonically-enhanced localization of light into photoconductive antennas," Proc. Conf. Lasers and Electro-Optics, CFI2 (2010)
13. H. Tanoto, J. Teng, Q. Wu, M. Sun, Z. Chen, S. Maier, B. Wang, C. Chum, G. Si, A. Danner, and S. J. Chua, "Greatly enhanced continuous-wave terahertz emission by nano-electrodes in a photoconductive photomixer," Nat. Photonics **6**(2), 121–126 (2012).

#175240 - $15.00 USD Received 30 Aug 2012; revised 20 Oct 2012; accepted 20 Oct 2012; published 25 Oct 2012

14. A. Geissler, M. He, J.-M. Benoit, and P. Petit, "Effect of hydrogen pressure on the size of nickel nanoparticles formed during dewetting and reduction of thin nickel films," J. Phys. Chem. C **114**(1), 89–92 (2010).
15. Y.-J. Oh and K.-H. Jeong, "Glass nanopillar arrays with nanogap-rich silver nanoislands for highly intense surface enhanced Raman scattering," Adv. Mater. (Deerfield Beach Fla.) **24**(17), 2234–2237 (2012).
16. S. Yang, F. Xu, S. Ostendorp, G. Wilde, H. Zhao, and Y. Lei, "Template-confined dewetting process to surface nanopatterns: fabrication, structural tunability, and structure-related properties," Adv. Funct. Mater. **21**(13), 2446–2455 (2011).
17. K. W. Vogt and P. A. Kohl, "Gallium arsenide passivation through nitridation with hydrazine," J. Appl. Phys. **74**(10), 6448–6450 (1993).
18. P. R. West, S. Ishii, G. V. Naik, N. K. Emani, V. M. Shalaev, and A. Boltasseva, "Searching for better plasmonic materials," Laser Photon. Rev. **4**(6), 795–808 (2010).
19. K. R. Catchpole and A. Polman, "Plasmonic solar cells," Opt. Express **16**(26), 21793–21800 (2008).
20. F. Stietz, J. Bosbach, T. Wenzel, T. Vartanyan, A. Goldmann, and F. Trager, "Decay times of surface plasmon excitation in metal nanoparticles by persistent spectral hole burning," Phys. Rev. Lett. **84**(24), 5644–5647 (2000).

1. Introduction

Terahertz (THz) radiation of 0.1 to 10 THz falls in the frequency gap between the infrared and microwaves. THz emission spectra have received much attention with technological advance such as high-power THz generation, THz imaging, and THz time-domain spectroscopy (TDS) [1]. In particular, THz pulses have many advantages in investigating material fingerprints through THz TDS because they can provide rich spectral information of diverse biochemical molecules at intermolecular or vibrational energy band [2–4]. However, THz technology has some technical limitations in a water-rich environment such as *in-vivo* biomedical applications due to high absorption from water molecules [5]. THz TDS with a reflection type can serve as an alternative method [6]; however, it still requires a high power terahertz emission source.

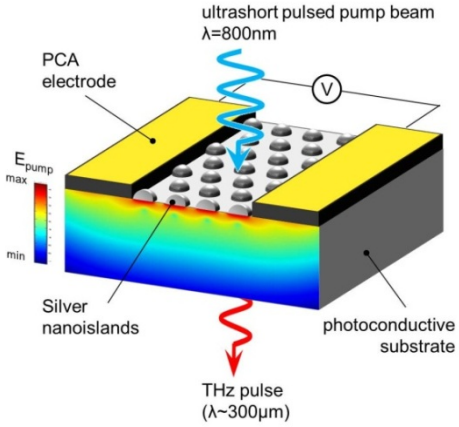

Fig. 1. A schematic diagram of nanoplasmonic photoconductive antenna (NP-PCA) with metal nanoislands. Plasmonic nanoislands are fabricated over the full photoconductive area to locally enhance the ultrashort pulsed pump beam. This local field enhancement increases photocarrier generation and THz pulse emission from the PCA.

Photoconductive antennas (PCAs) with an ultrashort pulse laser excitation are widely used as THz emission sources. THz pulse emission can be enhanced by incorporating either photoconductive materials with high acceleration of photo-excited carriers such as low-temperature grown gallium arsenide (LT-GaAs) [7,8] or by implementing constructive large-area excitation with inter-digital antennas and microlens arrays [9,10]. Recently, nanophotonics enables the enhancement of THz pulse emission by employing plasmonic nanoantennas between PCA electrodes [11–13]. The plasmonic nanostructures enhance the electric field of an ultrashort pulsed pump beam at localized surface plasmon resonance (LSPR). This local field enhancement increases photocarrier generation and THz pulse

#175240 - $15.00 USD Received 30 Aug 2012; revised 20 Oct 2012; accepted 20 Oct 2012; published 25 Oct 2012