Metamaterials Laboratory
Chief Scientist: Takuo Tanaka (D.Eng.)

(0) Research field

CPR Subcommittee: Engineering

Keywords:
Metamaterials, Nanophotonics, Plasmonics, Optics and Photonics, Spectroscopy

(1) Long-term goal of laboratory and research background

In the past, it has been believed that the electro-magnetic properties of materials are determined by the intrinsic property of the materials itself and no one can alter them. In this research laboratory, we are intensively investigating the breakthrough science and technologies that can artificially control the optical properties of the materials by using metal nano-structures. This technology can create unprecedented optical materials such that it can interact directly with the magnetic components of the light, in which the refractive index can be zero, negative or tremendously giant values. We collectively call these kinds of artificial materials - "metamaterials". We will also extend the application of metamaterials to develop novel and functional optical devices that will open a door for new photonic technologies.

(2) Current research activities (FY2021) and plan (until Mar. 2025)

Three-dimensional (3D) printing has revolutionized manufacturing processes for electronics, optics, energy, robotics, bioengineering, and sensing. Downscaling 3D printing will enable applications that take advantage of the properties of micro- and nanostructures. However, existing techniques for 3D nanoprinting of metals require a polymer–metal mixture, metallic salts or rheological inks, limiting the choice of material and the purity of the resulting structures. Aerosol lithography has previously been used to assemble arrays of high-purity 3D metal nanostructures on a prepatterned substrate, but in limited geometries. Here we introduce a technique for direct 3D printing of arrays of metal nanostructures with flexible geometry and feature sizes down to hundreds of nanometres, using various materials. The printing process occurs in a dry atmosphere, without the need for polymers or inks. Instead, ions and charged aerosol particles are directed onto a dielectric mask containing an array of holes that floats over a biased silicon substrate. The ions accumulate around each hole, generating electrostatic lenses that focus the charged aerosol particles into nanoscale jets. These jets are guided by converged electric-field lines that form under the hole-containing mask, which acts similarly to the nozzle of a conventional 3D printer, enabling 3D printing of aerosol particles onto the silicon substrate. By moving the substrate during printing, we successfully print various 3D structures, including helices, overhanging nanopillars, rings and letters. In addition, to demonstrate the potential applications of our technique, we printed an array of vertical split-ring resonator structures. In combination with other 3D-printing methods, we expect our 3D-nanoprinting technique to enable substantial advances in nanofabrication. This research results were published in nature.

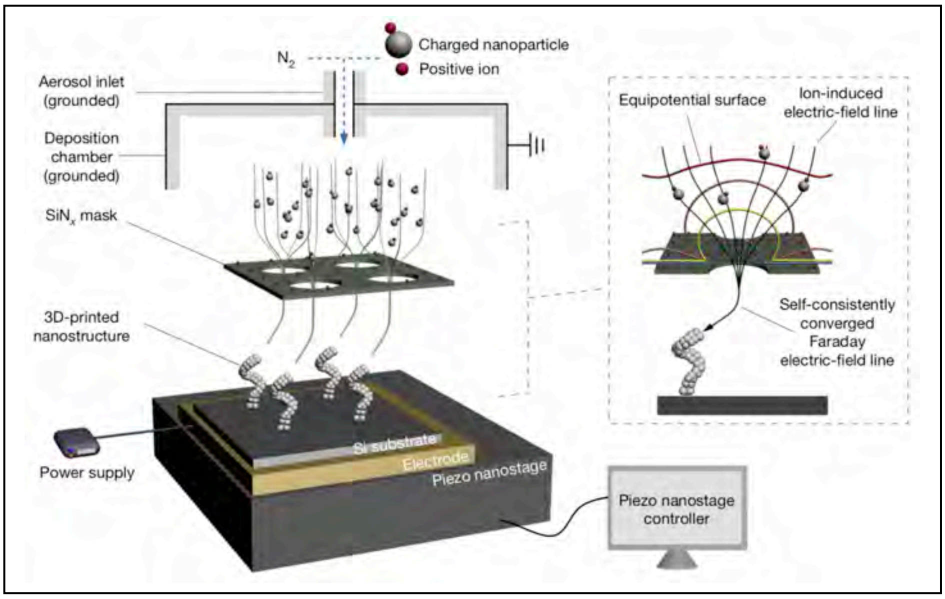

Fig. 1 Schematic of the 3D-nanoprinting setup, which consists of a nanoparticle (aerosol) source, a mask and a piezoelectric nanostage. Cations accumulated on the surface of the dielectric mask distort the originally flat equipotential surfaces around each hole in the mask into convex ones, generating a nanoscale electrostatic lens. As a result, charged aerosols are focused and guided along the self-consistently converged Faraday electric-field line that ends at the tip of the growing structure.

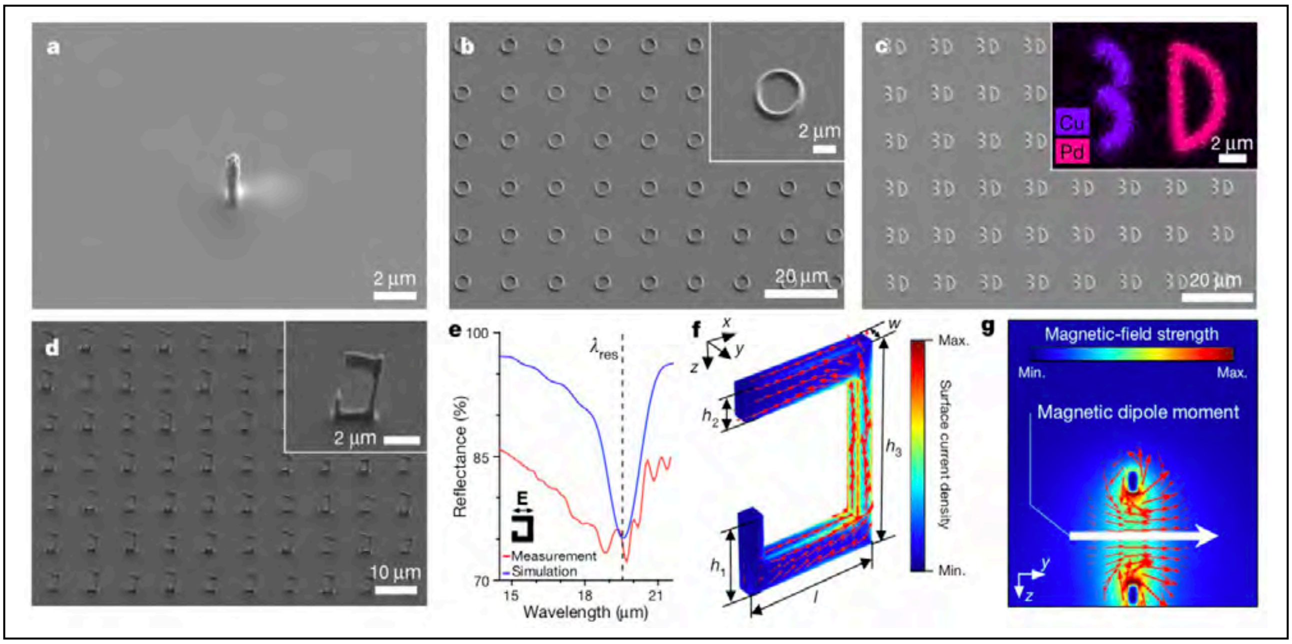

Fig. 2 Printing in surface-writing mode and optical characterization of 3D plasmonic metamaterials. (a) Scattered nanoparticles on the right-hand side of a nanopillar. (b) Ring structures printed by repeatedly moving the nanostage in a circle. (c) Numbers and letters (‘3D’) written on a substrate via programmed movement of the nanostage. (d) SEM image of an array of vertical SRRs, with a period of 9.2 µm. (e) Measured (red) and simulated (blue) reflection spectra for linearly polarized light. (f) Simulated surface current density under x-linearly polarized light at its resonant wavelength. (g) Magnetic-field distribution of the vertical SRR.

(3) Members as of March, 2021

(Chief Scientist)
Takuo Tanaka
(Visiting Scientist)
Taka-aki Yano, Ryo Kato, Tamotsu Zako, Nobuyuki Takeyasu, Shunsuke Tomita, Noriho Kamiya, Che-Chin Chen, Renilkumar Mudachathi,
(Student Trainee)
Taeko Matsukata, Shohei Maekawa, Kumiko Koide, Taichi Hara, Akari Kurata, Takuya Asakura, Mahiro Horikawa, Hiroyuki Abe, Subaru Ito, Shun Matsuzawa, Shunki Yatabe, Toshinari Odaka, Toshiki Sogawa, Song Subin, Yuki Takeuchi, Masayuki Fujiwara
(Assistant)
Yi-Jung Liang

(4) Representative research achievements

1. "Plasmon-Enhanced Solar-Driven Hydrogen Evolution Using Titanium Nitride Metasurface Broadband Absorbers," Meng-Ju Yu, Chih-Li Chang, Hao-Yu Lan, Zong-Yi Chiao, Yu-Chia Chen, Ho Wai Howard Lee, Yia-Chung Chang, Shu-Wei Chang, Takuo Tanaka, Vincent Tung, Ho-Hsiu Chou, and Yu-Jung Lu, ACS Photonics **8**, 3125-3132 (2021)
2. "Molecular Monolayer Sensing Using Surface Plasmon Resonance and Angular Goos-Hänchen Shift," Cherrie May Olaya, Norihiko Hayazawa, Maria Vanessa Balois-Oguchi, Nathaniel Hermosa, and Takuo Tanaka, Sensors **21**, 4593 (2021).
3. "Varifocal Metalens for Optical Sectioning Fluorescence Microscopy," Yuan Luo, Cheng Hung Chu, Sunil Vyas, Hsin Yu Kuo, Yu Hsin Chia, Mu Ku Chen, Xu Shi, Takuo Tanaka, Hiroaki Misawa, Yi-You Huang, and Din Ping Tsai, Nano Letters **21**, 5133-5142 (2021).
4. “Metamaterial perfect absorber simulations for intensifying thermal gradient across a thermoelectric device," Shohei Katsumata, Takuo Tanaka, and Wakana Kubo, Optics Express **29**, 16396-164065 (2021).
5. "Three-dimensional nanoprinting via charged aerosol jets," Wooik Jung, Yoon-Ho Jung, Peter V. Pikhitsa, Jicheng Feng, Younghwan Yang, Minkyung Kim, Hao-Yuan Tsai, Takuo Tanaka, Jooyeon Shin, Kwang-Yeong Kim, Hoseop Choi, Junsuk Rho, and Mansoo Choi, nature **592**, 54-59 (2021).
6. “Transient transmission of THz metamaterial antennas by impact ionization in a silicon substrate,” Matias Bejide, Yejun Li, Nikolas Stavrias, Britta Redlich, Takuo Tanaka, Vu D. Lam, Nguyen Thanh Tung, and Ewald Janssens, Optics Express **29**, 170-181 (2020).
7. “Angular Goos-Hänchen shift sensor using gold film enhanced by surface plasmon resonance,” Cherrie May Olaya, Norihiko Hayazawa, Nathaniel Hermosa, and Takuo Tanaka, The Journal of Physical Chemistry Part A **125**, 451-458 (2021).

Laboratory Homepage
https://www.riken.jp/en/research/labs/chief/metamaterials/index.html
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