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 (FY2019) and plan (until Mar. 2025)

Phonons provide information on the physicochemical properties of a crystalline lattice from the material's vibrational spectrum. Optical phonons, in particular, can be probed at both micrometre and nanometre scales using light-based techniques, such as, micro-Raman and tip-enhanced Raman spectroscopy (TERS), respectively. Selection rules, however, govern the accessibility of the phonons and, hence, the information that can be extracted about the sample. Herein, we simultaneously observe both allowed and forbidden optical phonon modes of defect-free areas in monolayer graphene to study nanometre scale strain variations and plasmonic activation of the Raman peaks, respectively, using our home-built TERS system in ambient. Through TERS imaging, strain variations and nanometer-sized domains down to 5 nm were visualized with a spatial resolution of 0.7 nm (Fig.1). Moreover, such subnanometric confinement was found to activate not only the *D* and *D'* forbidden phonon modes but also their *D+D'* combination mode (Fig. 2). With our TERS in ambient system, the full phonon characterization of defect-free graphene and other 2D nanomaterials is now possible, which will be useful for subnanometer strain analysis and exploring the inherent properties of defect-free materials.

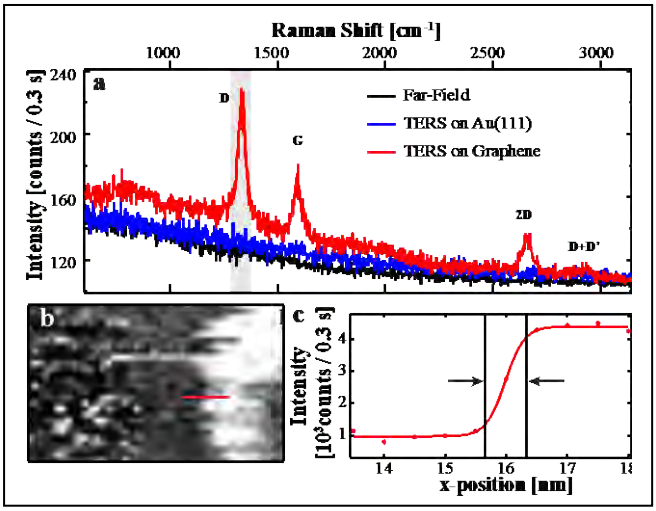

Fig. 1 (a) Tip-enhanced Raman spectra from defect free graphene and (b) its imaging based on D-band (scan area: 23nm × 14nm). (c) the cross-section plot at the red line in (b) shows sub-nanometric spatial resolution.

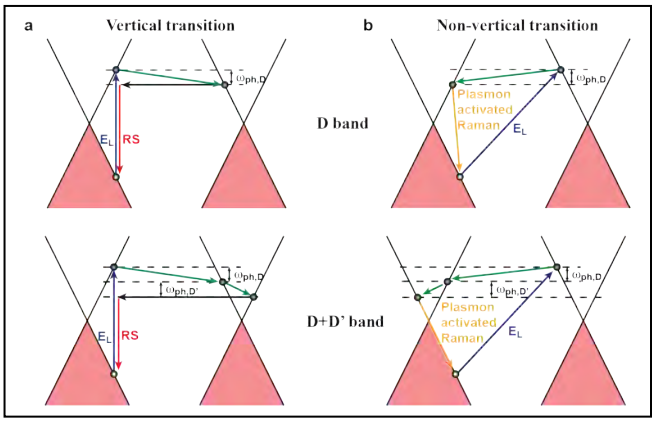

Fig. 2 (a) Activation of D and D+D' bands by a defect based on vertical transitions. (b) Activation of D and D+D' bands without defect based on non-vertical transitions.

(3) Members as of March, 2020

(Chief Scientist)
Takuo Tanaka

(Visiting Scientist)
Yukie Yokota, Takaaki Yano,
Che-Chin Chen,
Renilkumar Mudachathi,
Tomohiro Amemiya, Akihiro Takezawa

(Student Trainee)
Taeko Matsukata, Shohei Maekawa,
Kumiko Koide, Taiki Okada,
Taichi Hara, Akari Kurata,
Tomohisa Isegawa, Mahiro Horikawa,
Shohei Katsumata, Yoshiki Oda, Satoko Yagi

(Assistant)
Yi-Jung Liang

(4) Representative research achievements

1. "Ultrasensitive and Selective Gas Sensor Based on a Channel Plasmonic Structure with an Enormous Hot-spot Region," D.-S. Su, D. P. Tsai, T.-J. Yen, and T. Tanaka, ACS Sensors **4** (2019) 2900-2907.
2. "Selection and Visualization of Degenerate Magnetic and Electric Multipoles up to Radial Higher Orders by Cathodoluminescence," T. Matsukata, N. Matthaiakakis, T. Yano, M. Hada, T. Tanaka, N. Yamamoto, and T. Sannomiya, ACS Photonics **6** (2019) 2320-2326.
3. "3D Conical Helix Metamaterial based Isotropic Broadband Perfect Light Absorber," R. Mudachathi and T. Tanaka, Opt. Express **27** (2019) 26369-26376.
4. "Visualization of subnanometric local phonon modes in a plasmonic nanocavity via tip-enhanced Raman spectroscopy in ambient," M. V. Balois, N. Hayazawa, S. Yasuda, K. Ikeda, B. Yang, E. Kazuma, Y. Yokota, Y. Kim, and T. Tanaka, NPJ 2D Mater. Appl. **3** (2019) 38.
5. "Strengthen of magnetic anisotropy of Au/Co/Au nanostructure by surface plasmon resonance," Y. Kikuchi and T. Tanaka, Sci. Rep. **9** (2019) 8630.

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