平成 26 年 6 月 30 日

（独）理化学研究所
研究担当理事　川合 眞紀

平成 25 年度実施 准主任研究員の中間レビューの結果について

准主任研究員制度設置規定（平成 25 年規定第 14 号）に基づき准主任研究員の中間レビューを実施し、評価結果は以下のとおりです。

１．評価対象：田中メタマテリアル研究室．田中 拓男 准主任研究員

１）評価体制

実施日：平成 26 年 3 月 10 日（月曜日）
4 名の所外有識者を評価委員とするヒアリングレビューを実施(内 1 名は急遽メールレビューにて評価を実施)。

評価者：
Harry ATWATER, Professor
California Institute of Technology, U.S.A.

Makoto GONOKAMI, Professor
School of Science, The University of Tokyo, Japan

Masao KITANO, Professor
Graduate School of Engineering, Kyoto University, Japan

Kazuaki SAKODA, Professor
National Institute for Materials Science, Japan

２）評価結果の概要等

General comments:　（arranged in random order）

【Reviewer 1】

Research objectives: The research on metamaterials is currently quite an active and fascinating field, which may realize many innovative applications in the field of optical engineering. The particular research targets of the Metamaterials Laboratory are based on its unique nano-fabrication technologies for infrared and visible metamaterials that include the two-photon induced reduction of noble metal ions, the DNA-templating fabrication of gold trimer rings, the magnetic assembly of necklace structures of gold core-shell particles, and the isotropic metamaterials fabricated by the self-folding method. These objectives look fascinating and original enough to be the main research targets of the Metamaterials Laboratory.

Research results: The four above-mentioned technologies and some others were successfully applied to the fabrication of infrared and visible metamaterials. Their characterization by optical spectroscopy and electron microscopy showed a good agreement with theoretical calculations and predictions. These results have

appropriately been published and patented. A next important step seems to be the development of novel functionalities by means of those unique metamaterials.

Management of the Laboratory: The collaboration between the Associate Chief Scientist and his group members looks close and efficient. A few more staffs devoted to the development of novel functionalities may promote the application of their technologies.

Future research plans: Seven particular applications mentioned by the Associate Chief Scientist seem interesting and reasonably hopeful. Because of the limited manpower, the Metamaterials Laboratory may need closer collaboration than before with universities and companies to find a promising application.

Overall assessment: I found the nano-fabrication technologies of the Metamaterials Laboratory quite interesting and unique, which I believe should be developed further in the direction described in their future research plan.

Other opinions: None

【Reviewer 2】

Research objectives: The Metamaterials Laboratory aims at creating artificial structures with sizes comparable to or smaller than the wavelength of light. Such structures are expected to express optical properties that do not exist in nature, and provide chances to find new aspects of light-matter interaction and new functions to control light. As a result, new techniques for advanced use of light are created.
This research field is known as metamaterials, and its activities are rapidly growing world-wide in a wide wavelength region covering microwave, tera-hertz wave, and visible light.
The Tanaka Laboratory is particularly focused on developing new fabrication techniques to realize (1) 3D structure, (2) in a visible light region, and (3) with compatibility for cost-effective bulk production.

Research Results: The Laboratory developed a unique two-photon-induced reduction process, which is particularly powerful and can produce fine and high quality nano-structure on metallic materials, and is leading the field. Improvements of smooth surfaces employing the surfactant-assisted technique deserve special mention.
The DNA-templating method is expected to be a new direction, but is still in a developing stage.

Laboratory management: Dr. Tanaka respects the independence of young researchers, and encourages postdocs to take the initiative in pursuing their research while still keeping a considerable output level as a team. It is noted that the members of Tanaka Lab. had already been promoted to associate professor and in this respect too, the educational efforts are also highly evaluated.

On the other hand, the future direction of the research trend of the metamaterial field is

not necessarily clear, which is not necessarily a problem specific to Tanaka Laboratory, but a problem of the field of metamaterials.

The policy of RIKEN with respect to the Associate Chief Scientist System was not clear throughout the reviewing process. Particularly, all the positions of the researchers who belong to the Associate Chief Scientist's laboratory are limited term employees.

【Reviewer 3】

Research objectives: The Metamaterials Laboratory of RIKEN has responded to the intense worldwide interest and rapid growth of research activity in the field of metamaterials by positioning itself as a significant experimentally driven effort to develop new metamaterials concepts and fabrication approaches. The RIKEN Metamaterials laboratory is exploiting to excellent advantage both top-down and bottom-up fabrication methods for metamaterials, and is working to introduction new component materials into metamaterials motifs, while exploring new concepts and applications for metamaterials.

Research results: Since its inception in 2008, the Metamaterials Laboratory has been productive and has made several significant contributions to the metamaterials field. A particular highlight is the demonstration of large-scale synthesis of visible-frequency magnetic metamaterials using nanoimprint patterning techniques. This accomplishment is an important advance for the metamaterials community, which as a whole has generated many conceptual designs for metamaterials at visible frequencies, but which struggled to translate these concepts into experimental reality. Another unique accomplishment by the RIKEN Metamaterials Laboratory is the realization of three-dimensional metamaterials motifs via a two-photon photoreduction technique. Another highlight is the development of a three-dimensional polarization-insensitive metamaterial by utilization of self-folding bimetallic structures. In addition, the Laboratory has pursued metamaterials applications in several areas, including sensor development and photovoltaics.

Management of the Laboratory: The principal investigator has developed a successful management approach in which he is actively involved in laboratory organization and functions, and is an actively engaged mentor to the postdoctoral and student researchers under his supervision.

Future research plans: Future research will focus on applications of metamaterials in diverse applications including perfect absorbers and resonantly enhanced detection in infrared spectroscopy.

Overall assessment: The RIKEN Metamaterials Laboratory has made excellent progress towards its goal of realization of metamaterials concepts via top-down and bottom-up synthesis approaches, and holds considerable promise for future contributions to this burgeoning and exciting field. It has developed unique tools

and facilities for nanoscale materials synthesis and metamaterials fabrication, and well poised to address future research challenges using these capabilities.

【Reviewer 4】

Research objectives of Metamaterial Laboratory headed by Dr. Takuo Tanaka are to synthesize various types of metamaterials that can be utilized for lightwave control with new degrees of freedom. The research field of metameterial is quite new and a lot of activities are emerging. Utilizing metamaterials, one can manipulate waves with methods that are qualitatively different from conventional techniques.

Owing to the size scalability with respect to the wavelength, the performance of metamaterials can be initially confirmed in the region of microwaves or terahertz. Then they can be transferred to the optical regions for much wider applications. However, there are many obstacles to extend the confirmed methods to optical regions. Reducing the size of three-dimensional elements down below the wavelength is already a hard task. Moreover a huge number of elements have to be assembled to form a uniformly distributed material. Tanaka's group has undertaken such challenging tasks all the time. They have succeeded in fabricating various types of metamaterials in optical regions making use of state-of- the-art nanotechnology.

The respectable achievements of Tanaka's group in the last five years are well recognized by the community of metamaterial research. The contributions from the group are clearly presented and help people in the related fields to understand the importance of their results.

The laboratory has been well operated in terms of human resources and research budget. Fostering young researchers and the contribution to scientific outreach activities can be highly evaluated.

As for future plans, the elaboration of fabrication techniques of metamaterials should be the main subject of the group. Furthermore, the proposed extension of research area is reasonable and prospective.

以上