Fabrication of Artificial Crystal Architectures by Micro-manipulation of Spherical Particles

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Abstract

We newly designed and manufactured a new arranging system for a three-dimensional artificial crystal of monosized micro particles. In this system, a robotic micro-manipulator accurately locates the spherical particle onto the lattice point, and subsequently fiber lasers micro-weld the contact points between the neighboring particles. Actually, one- and two-dimensional arrays were constructed using monosized tin particles with the diameter of 400 m. Moreover, due to optimization of the process parameters, we successfully constructed the artificial crystals of simple cubic and diamond structures. In particular, the diamond structure which can represent a large photonic band gap is expected to progress toward a practical photonic crystal device.

Keywords : terahertz photonic crystals, particle arrangement, fiber laser, diamond structure

1. Introduction

3D periodic structure assembled from monosized spherical particles with a size of hundreds of micrometers can realize an ideal photonic crystal (PhC) for terahertz (10^{12}Hz) waves. Fortunately, recent advance in atomization techniques have accomplished mass-production for such monosized micro-particles.[1] Actually, the inverse f.c.c crystals that were derived from the self-assembled particle array were demonstrated to exhibit the particular effect of PhC, so-called photonic band gap (PBG), in terahertz wave regions.[2]

Among all the 3D periodic structure, the diamond structure is best adapted to practical devices because it possesses a wide PGB.[3] However, the non-closed-packed structures except f.c.c cannot be assembled without binding between adjacent particles due to their spatial instability. On the other side, even monosized particles are definite to have some size variation. As illustrated in Fig. 1(a), even if some binding technique is applied, the accumulation of the size deviation may cause a disorder of periodicity, which results in an attenuation of PBG.[4]

Therefore, we propose a new concept to achieve both the assembly of non-closed-packed structures and precision assembly as illustrated in Fig. 1(b). The diameter of each particle is first measured just before arraying, and put at a distance of the measured size deviation from an ideal lattice point. The contact points of adjacent particles are locally melted by laser irradiations. During melting, the subjected particle is relocated onto the ideal lattice point. As a consequence, the particle is strongly and precisely fixed on the lattice point after solidification.

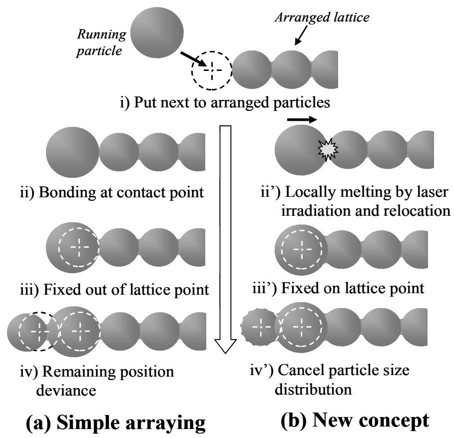

Fig. 1. Schematic illustration for influence of size distribution on array accuracy in simple arraying and new concept capable of cancellation of size deviation.

In this study, we first aimed to design and manufacture the particle array system based on the above concept. Furthermore, the assembly of 3-D artificial crystal architectures was challenged through the optimization of process parameters.

2. Design and manufacturing of particle array system

The newly designed and manufactured micro-particle array system is illustrated in Fig. 3. This system employs the pick-and-place robotics to precisely control the location of each particle. The constitutive particles are initially stored in the bucket. One particle is randomly chosen among them and its image is taken by a high resolution CCD camera. While the diameter of particle is analyzed from the image, a micro gripper with a piezo-driven claw picks and carries the particle to a specific point over the arraying stage. This stage then moves to locate the subjected particle onto the temporary lattice point calculated by the image analyzer. Subsequently, the fiber lasers with a focal diameter of 32 m irradiate all the contact points between the subjected particle and adjacent particles at the same time. The fiber lasers on a six-axis stage (a rotation angle, elevation angle, x, y and z) are capable of irradiation in any direction. The subjected particle is relatively relocated onto the ideal lattice point by re-motion of the arraying stage at a certain time in the irradiation. After bonding, the gripper releases the particle and returns to the bucket. A repeat of this sequential operation is expected to complete the particle architecture.

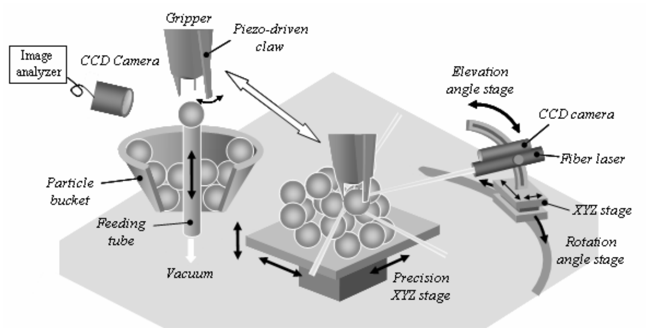

Fig. 2. Schematic illustration of the newly developed particle arraying system.

3. Experimental procedure

In order to understand the phenomenon on the laser bonding and optimize process conditions, 1D particle array was conducted with the manufactured system in advance of 3D-assembly. The tin monosized spherical particles with a diameter of 400 ±8 m were chosen as raw particles. The 1D arrays were arrayed in the height direction using one fiber laser by changing the laser power and duration. The equipped lasers are capable of emitting the IR with a power up to 9W. The obtained arrays were then observed by a scanning electron microscopy.

Base on the results of 1D array, we tried to assemble diamond structure. This assembly was carried out using 4 lasers corresponding to the number of neighboring particles.

4. Result and discussion

Fig. 3 shows an example of the 1D arrays obtained with the new system. The fiber laser bonding was demonstrated to give a strong binding, enough to retain the spatial instability. However, an excess irradiation caused distortion of particles due to excessive melting, which significantly affects the coordinate accuracy. In this study, the optimum laser conditions to avoid such a distortion were determined to be in the power range of 1-2W and the duration of around 100msec.

With the knowledge obtained on the 1D array experiment, we were successful in assembly of artificial crystals with diamond structure, as shown in Fig. 4.

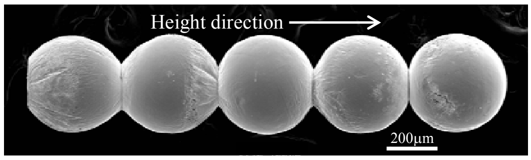

Fig. 3. SEM micrograph of the 1D array by irradiation of 1.2W for 100msec.

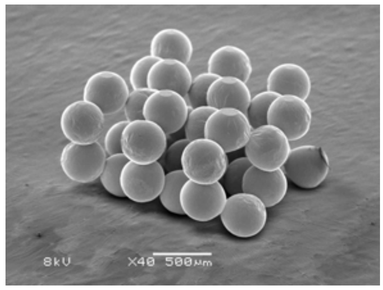

Fig. 4. SEM micrograph of assembled diamond crystal by the developed array system.

5. Summary

We designed and manufactured the new system capable of a highly accurate assembly for the non-closed packed crystals using monosized micro-particles. Actually, this system succeeded in fabricating the artificial crystals with diamond structure based on the process conditions obtained by 1D arraying.

6. References

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