Mid-Infrared Optical Sorting of Microparticles Composed of Si-O-Si Bonds

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1. Introduction

Mechanical control of microparticles using a laser is also known as optical manipulation, where radiation force is exerted on the particles through momentum transfer. In most of the previous works, near-infrared (NIR) lasers are conventionally used for optical manipulation studies since their wavelength region is transparent to the target particles. Moreover, with the aid of visible lasers, the radiation force (also induced polarization) is resonantly enhanced by exciting their electronic transition states.[1] However, visible and NIR show several drawbacks, such as photobleaching[1] and photothermal damage. Recently, we have examined the resonant effect of vibrational transition with mid-infrared (mid-IR) lasers, and silica microparticles were selectively sorted from the mixture solution by exciting their vibrational modes (Si-O-Si bonds) with a 9.3 μm quantum cascade laser (QCL).[2] Here, we employed an experiment with various materials (silica, TPM, PMMA, polystyrene) with different absorbances at 9.3 μm. We used the 9.3 μm QCL to manipulate and sort microparticles based on their intrinsic mid-IR vibrational properties. This method allows selective microparticle manipulation without sensitizer and simultaneously minimizes photodamage.

2. Experiment

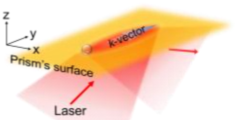

Figure 1. ATR setup.

We introduced a 9.3 μm QCL into an attenuated total reflection (ATR) setup to generate an evanescent field on the ZnSe prism surface. The generated evanescent field can accelerate particles within its field along the k-vector in Fig. 1. We used 5 μm silica, TPM ((3-trimethoxysilyl)propyl methacrylate))[3], PMMA, and polystyrene microparticles. TPM has a lower Si-O-Si bond density than silica due to the PMMA moieties in its structure, indicated by a lower absorbance value at 9.3 μm measured using the conventional ATR-FTIR method. PMMA and polystyrene particles are representatives of particles which contain no Si-O-Si bonds.

3. Results and Discussion

The particle velocity, radiation force, and absorbance value at 9.3 μm of each microparticle

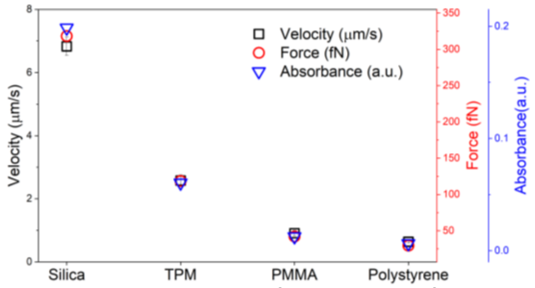

Figure 2. Summary of velocity, force, and absorbance of microparticles.

are summarized in Fig. 2. Each particle shows a different velocity, radiation force, and absorbance at 9.3 μm. Silica particles show the highest velocity due to the highest Si-O-Si bond density than other microparticles. TPM particles show lower velocity than silica due to PMMA moieties in their structures, i.e., lower Si-O-Si bond density indicated by low absorbance value. On the other hand, PMMA and polystyrene particles show the lowest velocity due to the absence of Si-O-Si bonds in their structure. PMMA was slightly faster than polystyrene due to the small absorbance from the -COC twisting mode. The velocity, force, and absorbance are in good agreement, indicating radiation force enhancement by molecular vibrational resonance. Moreover, a linear correlation between absorbance and velocity was observed and will be explained in detail in the presentation. These results indicate the specificity of the Mid-IR manipulation, where particles can be sorted based on the density of the Si-O-Si bond. The intrinsic molecular vibrational properties allow selective and efficient particle manipulation without adding sensitizers. Therefore, the specificity of this method provides a powerful method to manipulate particles with different molecular vibrational properties and densities, e.g., polymer particles, molecular aggregates, and microcrystals.

References

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