Observation of Helium Excimer Clusters Generated via Neutron-^{3}He Absorption Reaction

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1. Introduction

Turbulence is one of subjects which is scientifically and industrially important but whose detail remains unsolved by its complexity. Therefore, quantum turbulence, where vortices are quantized, has been expected to be a key to solve the physics of turbulence, in addition to scientific interests on the nature specific of quantized vortices. To study quantum turbulence existing in superfluid ^{4}He, recently flow visualization using triplet metastable ^{4}He molecules (excimers) He_2^* as a tracer was emerged to be a new method which provides us information on normal-component flow individually [Marakov et al., Phys. Rev. B (2015)]. However, complete observation of the velocity fields in turbulent superfluid ^{4}He requires localized small clouds of He_2^* excimers, *clusters*, of which generation method has not been established so far. Thus, to realize such excimer clusters, we proposed the use of the neutron absorption reaction ^{3}He(n,p)^{3}H of ^{3}He impurities contained in liquid ^{4}He, where ^{1}H and ^{3}H resulted by the reaction have sufficient energy to excite ^{4}He atoms for excimer generation. And, we started the proof-of-principle experiments using the neutron beam of J-PARC/MLF.

As the first step, in previous experiment (Project No. 2016B0111), we found that the application of neutron beam increases the signal suggesting He_2^* excimer generation, but the reproducibility and stability were not sufficient for detailed analyses. Therefore, we improved the detection system as shown in the next section. Thus, this experiment was conducted to obtain the proof of excimer generation via neutron-^{3}He absorption reaction by quantitative analyses of improved experimental data.

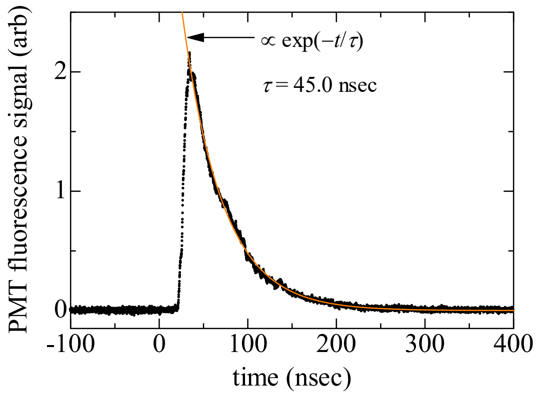
2. Experiment

The sample liquid helium was stored in a stainless Dewar with four quartz optical windows at the bottom part. By depressurizing of it, the temperature of liquid helium was kept at 1.8-1.9 K below the superfluid transition temperature in order to avoid disturbance by vapor bubbles, and a neutron beam with a cross section 20 × 20 mm^2 was applied into liquid ^{4}He thorough a pair of the optical windows. Commercially-available liquid ^{4}He usually includes 0.3 ppm of ^{3}He as isotopic impurities. By absorption of a neutron, the ^{3}He atom splits into ^{1}H and ^{3}H with an energy of 764 keV, which is expected to ionize ^{4}He atoms along their track, and generate a cluster consisting of typically 10^4 He_2^* excimers. For detection of these excimers, 905 nm laser pulses with cross section 8-20 mm^2 were applied in the center of the neutron beam in parallel, to excite 640 nm fluorescence of the excimers. And then, the fluorescence was observed by photomultiplier tubes (PMT) using the bandpass filter selectively, through two optical windows placed in the direction perpendicular to the neutron and laser beams.

To create the 905 nm laser pulses for fluorescence excitation in our system, 532 nm Nd:YAG laser pulses are converted via a resonator using a Ti-sapphire crystal. Before this experiment, we improved this converter for much more stable and larger photon density in pulses than the previous setup. In addition, for repumping cw laser to help excimers to return the ground state, 1064 nm was added to the previous 1085 nm, to cover a wider wavelength range. Faster data acquisition system for PMT was also prepared to take a statistically meaningful amount of data.

3. Results

As a result, the improved excimer detection system showed a very good performance with high stability and reproducibility during whole the experiment. The excitation laser intensity was confirmed to be sufficient to make an appropriate laser sheet, which enables us to visualize the velocity field in superfluid ^{4}He in future.



The figure shows a typical He_2* excimer fluorescence signal observed by PMT, where 2000 events triggered by the 905nm excitation laser pulse were averaged. Since smaller amount of photons were always observed accompanying the excitation pulse even when neutrons were absent, those were subtracted as a background. In the figure, spike signals of each photons were averaged, so that this envelope indicates the probability of photon emission from the excited state of He_2* excimers. The time constant, τ in the figure, was obtained to be 40-46 nsec for various experimental conditions, which corresponds to the lifetime of the excited state. The value agrees with 48 ± 2 nsec appearing in a literature [Rellergert et al., Phys. Rev. Lett. (2008)], which shows that this signal is fluorescence of He_2* eximers.

When the neutron flux was changed by the selection of upstream collimators and shutters on the beamline, the intensity of fluorescence was observed to be proportional to the neutron flux, which clearly indicates that these He_2* excimers were generated by neutrons. On the other hand, to confirm that these He_2* excimers are generated via ^{3}He(n,p)^{3}H reaction, contribution of γ ray accompanying the neutron beam must be excluded, because they also generate excimers via the Compton effect on all ^{4}He atoms. By control experiments using the B4C blocker on the beamline, these γ ray contributions were estimated to be 40% at most. Thus, the main contributor to generate He_2* excimers were confirmed to be the ^{3}He(n,p)^{3}H reaction.

From the obtained PMT signal intensity, the number of He_2* excimer clusters in the steady state are estimated to be at least about 170 clusters/cc for the neutron flux of 3.7×10^5 n/sec/cm^2, which are considered to be sufficient for tracers to visualize the flow field in superfluid ^{4}He.

4. Conclusion

We have confirmed that He_2* excimer clusters are generated via the neutron absorption reaction of ^{3}He impurities existing in liquid ^{4}He, and that they can be detected by the laser-induced fluorescence. The laser system to excite fluorescence of excimers was also confirmed to have sufficient power towards visualization of complete flow field in turbulent superfluid ^{4}He in future. Thus, for a next step, we will advance preparation to capture the real image of a He_2* excimer cluster generated by the ^{3}He(n,p)^{3}H reaction, using a video camera with high sensitivity.