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Laser-Induced Dynamics of Nano-Energetic Systems via In-situ TEM

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Nano-energetic materials store chemical energy at the nanoscale and are composed of nano-sized fuels and oxidizers. They are broadly classified as propellants, explosives, and pyrotechnics based on the energy release of the systems; propellants and pyrotechnics have low reaction rates, whereas detonation occurs in the explosives because of high reaction rates. Modern-day propellants utilize Aluminum nanoparticles (Al NPs) as a fuel because of its low ignition, reduced heat and mass diffusion, and fast energy rates.[1,2] Usually, metal fuel and oxidizer are embedded in the polymer binder to create a propulsion system that combusts upon ignition.

In recent years, fluoropolymers have been used as a binder because fluorine can quickly react with metal fuels resulting in strong oxidation without separately adding the oxidizer.[3] Amongst the fluoropolymers, polyvinylidene fluoride (PVDF) has excellent mechanical strength, chemical stability, and solubility in some organic solvents, because of which it is a great candidate for the binder. As a result, Al NPs and PVDF make up the ideal system to investigate the combustion dynamics at the nanoscale. The surface of Al NPs is extremely active, which results in a thin passivation layer of Al_2O_3 around the Al NPs. It has been reported that the fluorination of Al_2O_3 (-273.2 kJ/mol) followed by fluorination of core Al (-1209kJ/mol) is an exothermic process that results in the formation of AlF_3.[2] Despite the number of studies done for the Al NPs/PVDF system, there is a knowledge gap in understanding the structural changes that occur during the chemical reaction over an extremely small scale of space and time. This can be accomplished by in-situ transmission electron microscopy methods.

In this study, the state-of-the-art in-situ transmission electron microscope (TEM) equipped with the laser system, as shown in figure 1, is used to capture the reaction dynamics.[4] In the in-situ laser heating mode, the sample is excited with nanosecond pulsed laser while simultaneously capturing the reaction dynamics with electron beam imaging with high spatial resolution. The focus of this study is to identify the products formed as a result of the chemical reaction between Al NPs and PVDF and obtain the transient morphological structures as the reaction evolves, as shown in figure 2. This presentation will discuss in-situ TEM reaction dynamics, diffraction and spectroscopic analysis of reactants and products. Additionally, the transient analysis will provide new insights into controlling the reaction dynamics, which will provide information that could be utilized to synthesize and process such systems for a given application [5].

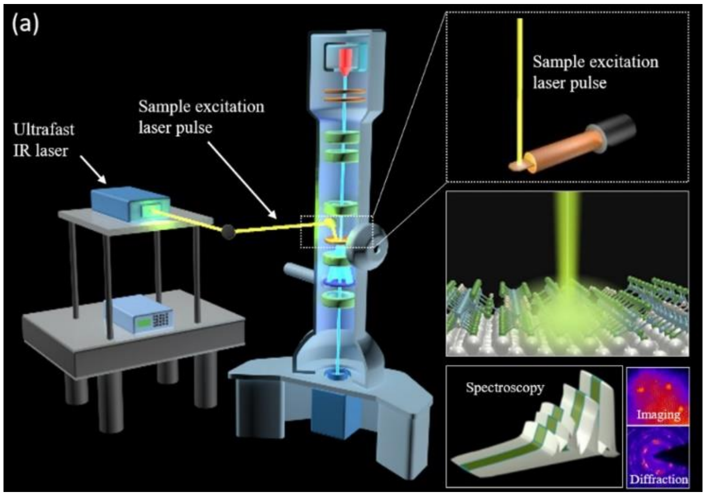

Figure 1. In-situ laser heating mode of modified 200 kV TEM

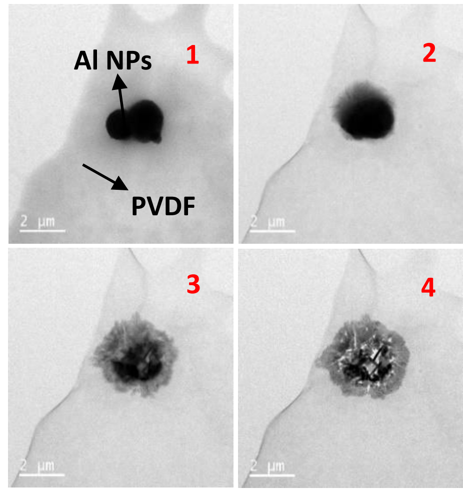

Figure 2. PVDF/Al NPs reaction evolution from 1→4 upon laser ignition

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