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Effect of titanium doping on the compositional homogeneity of hollow glass microsphere

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ABSTRACT

Titanium doped hollow glass microspheres (HGMs) were fabricated by sol-gel method. There were two kinds of spheres, blue and colorless, in each batch of HGMs. To study the effect of titanium doping on the compositional homogeneity and the difference between the two classes of HGMs, titanium doped gel precursors and HGMs were characterized by XRD, XRF, SIMS, SEM and EDS. The results showed that precipitation of alkali chlorides reduced the uniformity of heavily doped gel precursors and increased the dispersions of doping concentration in batches of HGMs. Because of the movability and flowability at high temperature, the uniformities of alkali metals were relatively poor in all HGMs. The DSIMS depth profiles of HGMs showed that local loss and accumulation of glass network modifiers, especially alkali metals, occurred in the outer and inner surface layers in dozens of nanometers as a result of volatilization and migration in furnace. Titanium behaved as both glass network former and modifier and its uniformity was between that of alkali metals and silicon. In blue HGMs, crystallization and segregation of titanium oxide, furthermore, reduced the compositional homogeneity of blue spheres in comparison to that of the colorless one.

1. Introduction

Hollow glass microspheres (HGMs) are widely used as fuel containers in inertial confinement fusion (ICF) experiments, due to the advantages of high strength for holding deuterium-tritium (DT) gases, optical transparency that facilitates visible characterization and inspection, facility to fill and retain DT gases and so on [1–4]. In indirectly driven ICF experiments, the hohlraum X-ray ablates material from outer capsule surface, causing the capsule container to compress the DT fuel. The compression efficiency depends sensitively on the coupling of the X-ray drive to the capsule ablator [5,6]. The growth of hydrodynamic instabilities at the ablation-fuel interface, namely Rayleigh-Taylor (RT) instability, will result in breakup of the interface with an associated reduction in compression and yield [7,8]. The K-shell spectroscopy of medium or high atom number (Z) ablator dopants has been established to diagnose the compressed core, involving the implosion uniformity, temperature, and mixing of the ablation layer and fuel during different implosion phases [5,6,9–11]. In addition, it may allow the modification of density profile at the ablation front to reduce the growth rate of RT instability. The medium- or high-Z element helps to capture suprathermal electrons and shield them from preheating the fuel as well. For the recent diagnostic experiments, elements from $Z = 22$ to 26 (Ti–Fe) are desirable dopants. Owing to the advantages of safety, cheapness, lightness, high efficiency, and simplicity, HGMs are also promising high-pressure hydrogen storage containers [12–14]. The photo-accelerated hydrogen diffusion through HGMs doped with transition metals, (Fe, Co, Ni, etc.) provides a prospective solution to the poor hydrogen release rate, which hinders the further development of this efficient hydrogen storage technology [15–17].

Titanium is a particular diagnostic element and it brings about a relatively simple K-shell spectroscopic signal when the wall mixes into plasma [11,18]. Titanium uniformly doped HGMs in the shell are currently required by experimentalists for ICF diagnostic experiment. Moreover, it has been coincidently found to be optically active in our study and the gas filling and release could be controlled by illuminant, which has never been reported. The photo enhanced gas diffusion will facilitate the gas filling process both in ICF and hydrogen storage program. Non-uniform elements distribution is one of the causations for RT instability and asymmetrical implosion and as a result, they may subsequently reduce the capsule performance and energy gain in ICF experiments. Moreover, the compositional homogeneity of glass is also associated with the strength and permeability of HGMs. So, the compositional homogeneity is crucial for HGMs to be used as ICF container or hydrogen storage container.

Sol-gel method is one of the good techniques to fabricate HGMs. One of the advantages of this method is to introduce doping elements to give some special properties or improve the properties of HGMs [19–21]. In this work, titanium-containing gel precursors have been fabricated via

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sol-gel method. As has been reported, there are two classes of spheres, colorless and colored (blue and deep brown), for each batch of HGMs when doping level exceeds 5%. They are classified into class A and class B, respectively, based on the absorption of different visible light wavelengths. Coloration of the class B HGMs is caused by the formation of oxygen vacancy and that induced Ti^{3+} [22]. Since the brown sphere is scarce, class B HGMs for research in this work means the blue one unless otherwise specified. To investigate the influence of titanium doping on the compositional homogeneity of HGMs, the uniformity of titanium doped gel precursors and HGMs with different doping levels were characterized by XRF, SEM-EDS, XRD, SIMS, et al. Elements distribution both in the spherical surface and in the radial direction of glass shells were tested. In addition, the differences between the two kinds of HGMs in the same batch were compared.

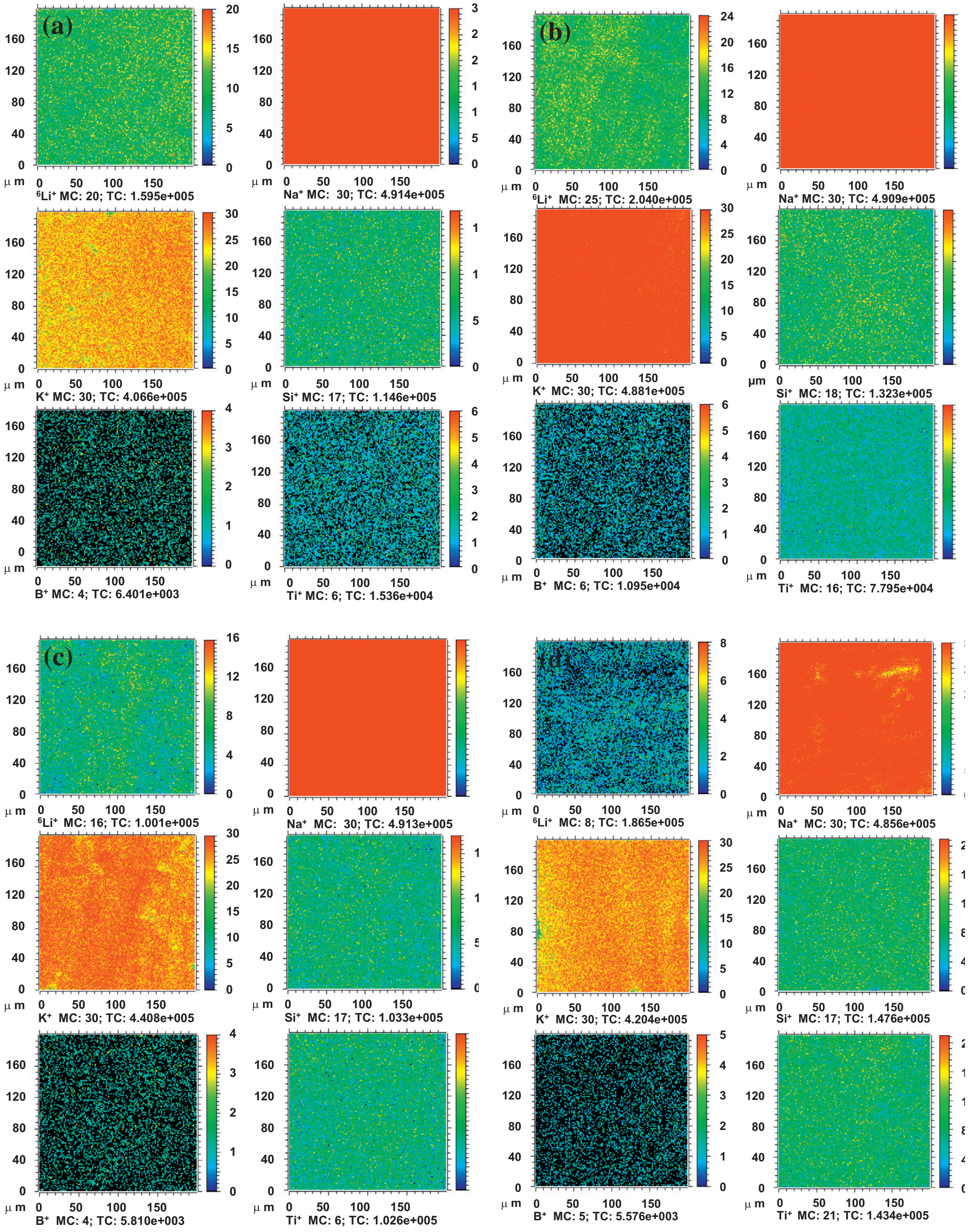

Fig. 1. SIMS ion images of titanium doped gel grains with different doping levels: (a) 5%, (b) 10%, (c) 15%, and (d) 20%.