

On the Host Lattice Lu₃Al₅O₁₂ Doped by Trivalent Neodymium as a Transparent Laser Gain Material

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Background

Optically transparent ceramics have become more and more important on an industrial scale over the last few years, i.e. as cost efficient substitutes in PET scanners, lens materials or scintillators. Their continuous rise to prominence is mainly due to their many advantages compared to single crystals, such as tailor-made dopant gradients and versatile dopant combinations at lower costs and with superior material features.

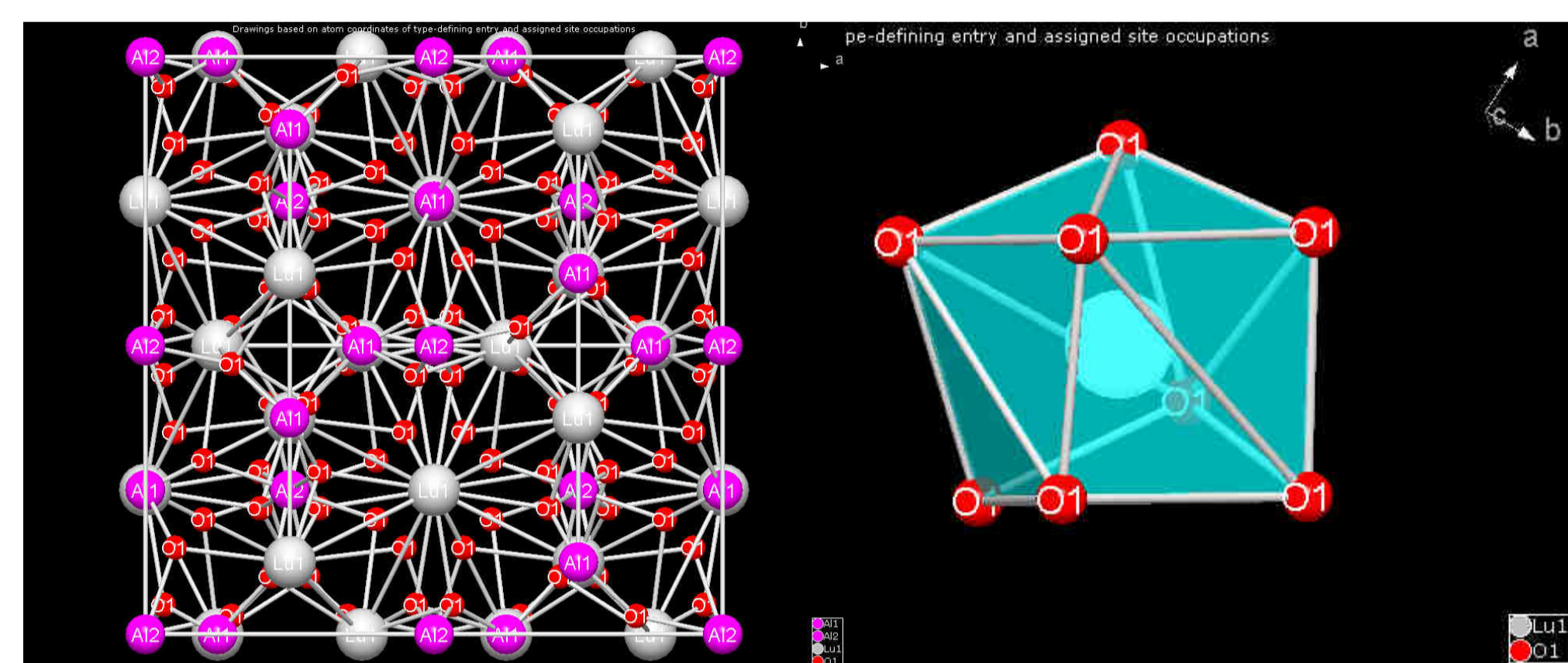


Fig. 1 Crystal structure of Lu₃Al₅O₁₂

In this study, the garnet system Lu₃Al₅O₁₂ (LuAG) was examined and it was tried to obtain transparent ceramics with minimized scattering at grain boundaries and cavities, thus with a high theoretical density (>99.9%). The cubic crystal structure (Ia-3d), preferable because of the refractive index being isotropic (1.84 @588 nm), its chemical stability and its hardness make LuAG the host lattice of choice. Furthermore, it exhibits a thermal conductivity of 8.0 W/mK and a low thermal expansion coefficient of 8.8 ppm/K. It is also a well-known laser medium with a density of 6.72 g/cm³ and a high melting point of approx. 2060 °C.

Usually, LuAG used as a laser medium is doped with either Yb or Nd, but in this study LuAG was doped exclusively with Nd. Versatile methods and measurements were carried out in order to gain information on the dependence of density and luminescence, respectively, on particle size and pressure.

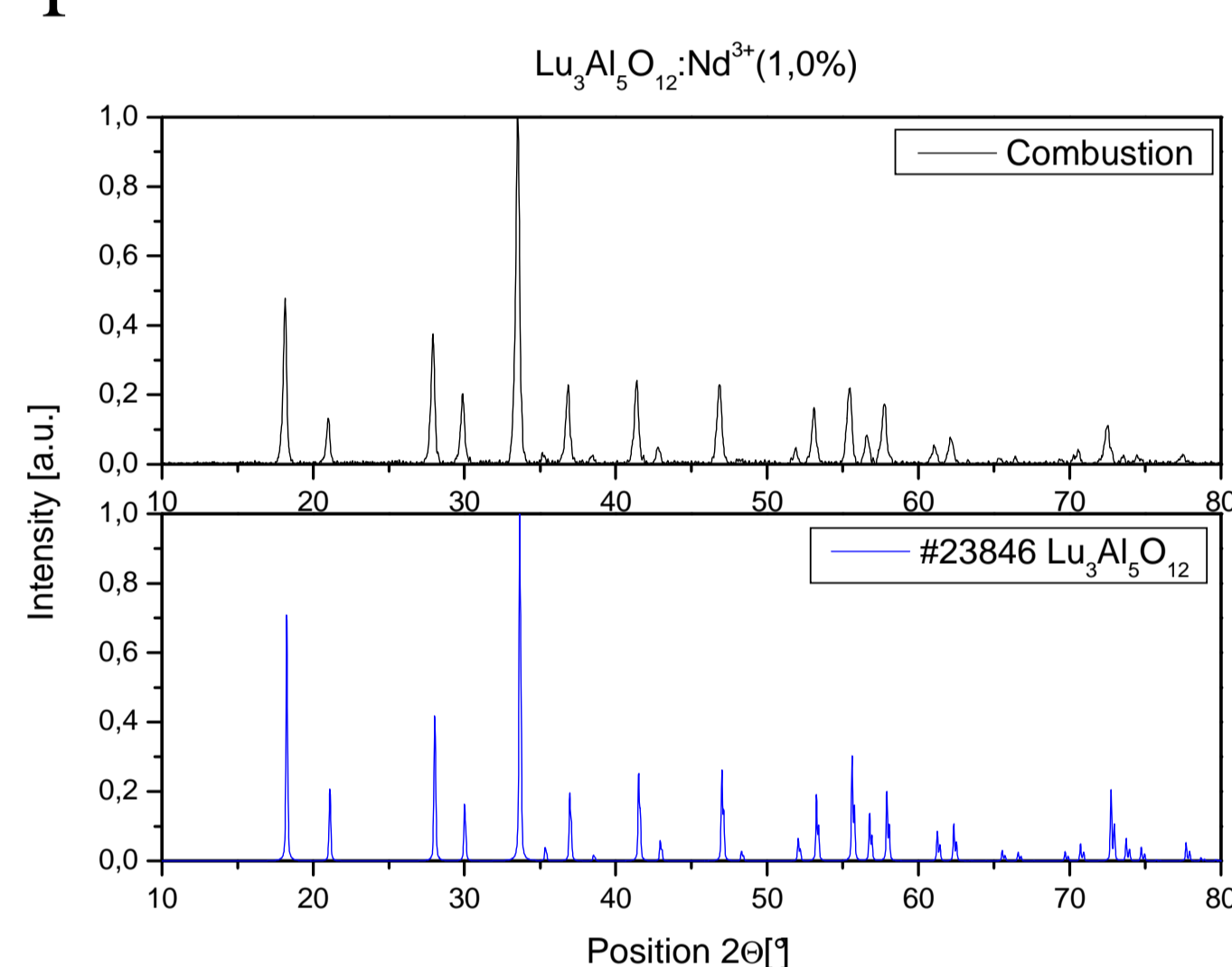


Fig. 2 Powder diffraction pattern of combustion sample

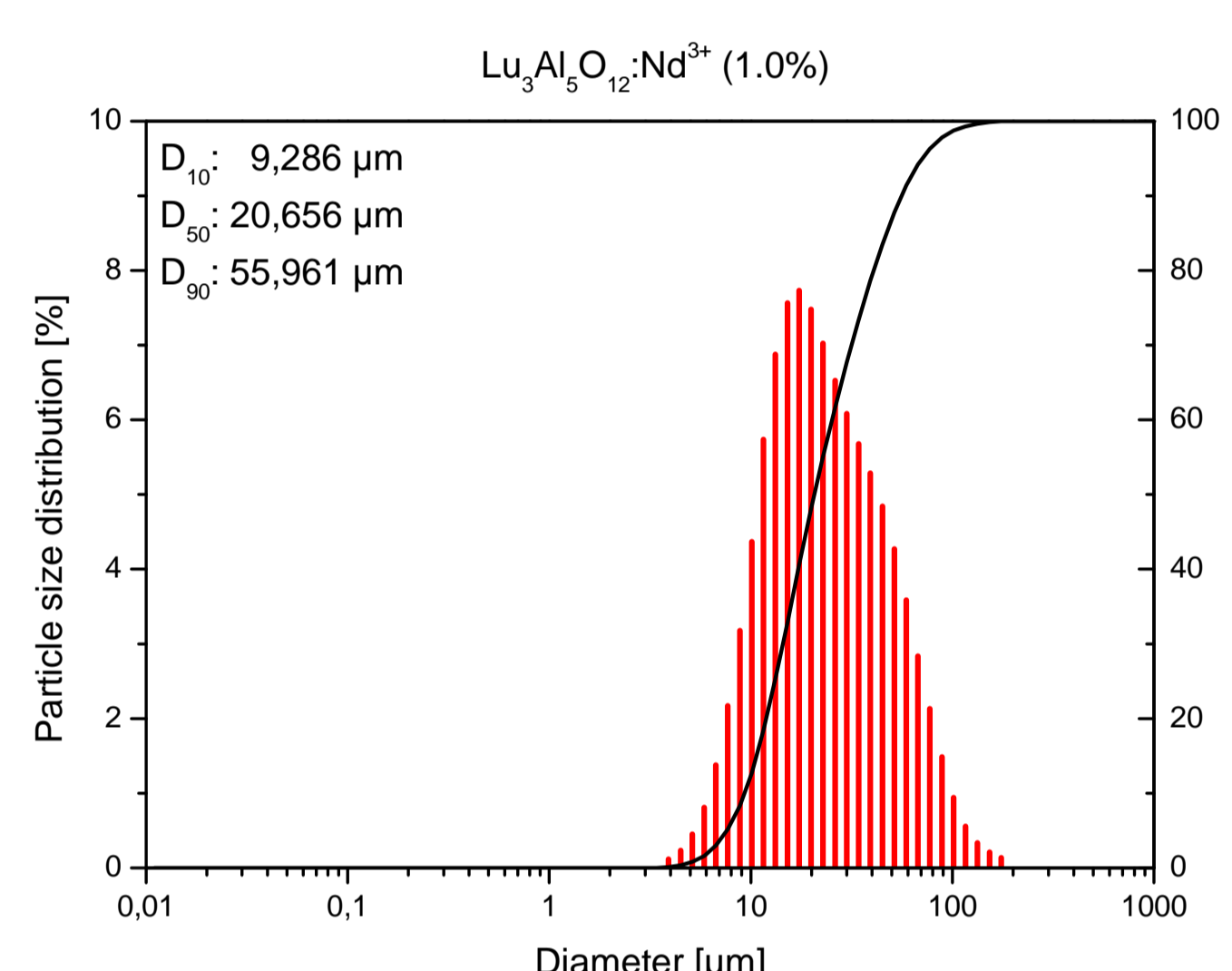


Fig. 3 Particle size distribution of combustion powder sample

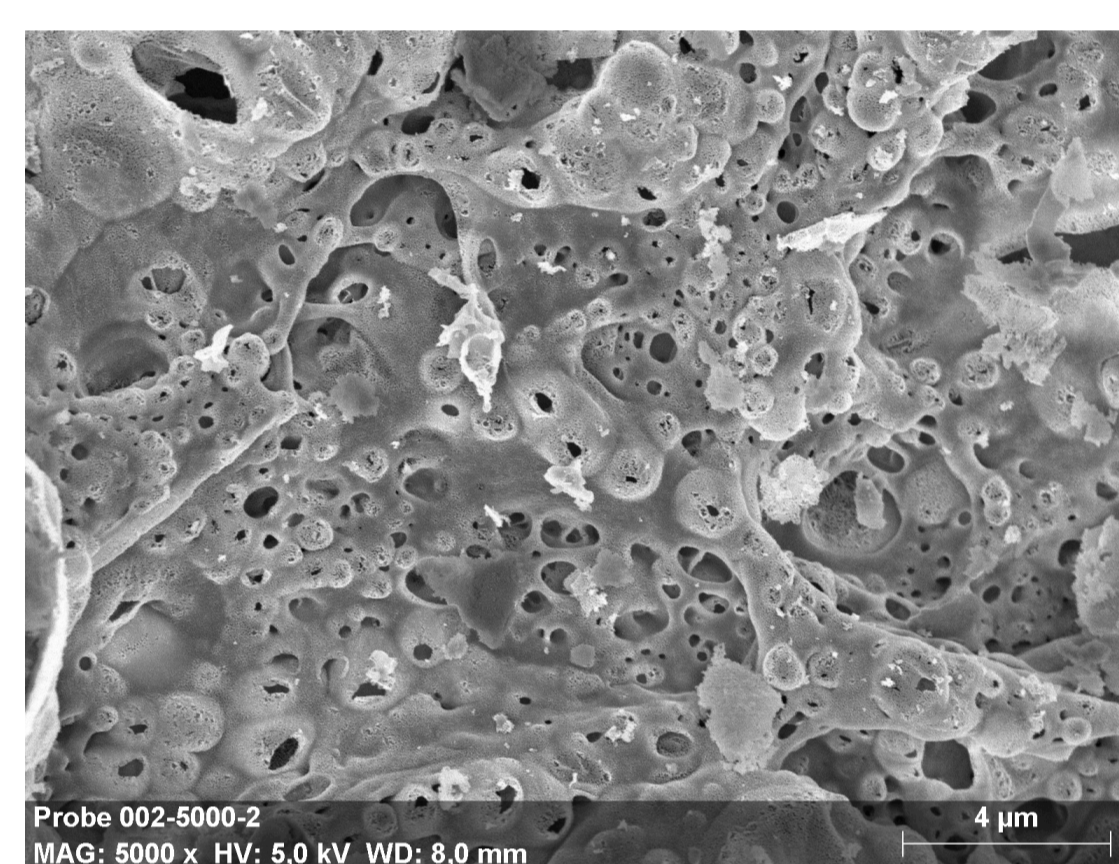


Fig. 4 SEM image of combustion powder sample

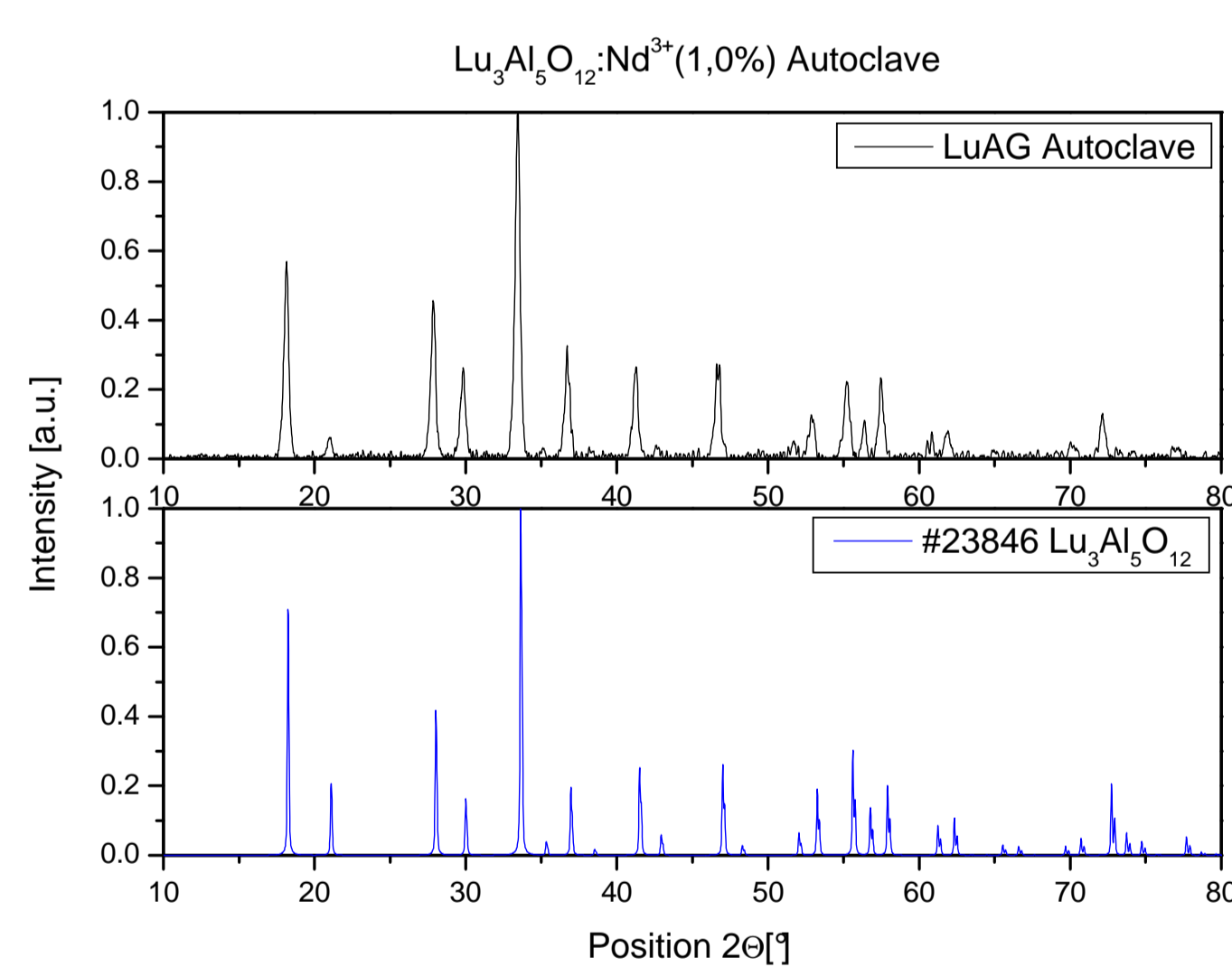


Fig. 5 Powder diffraction pattern of autoclave sample

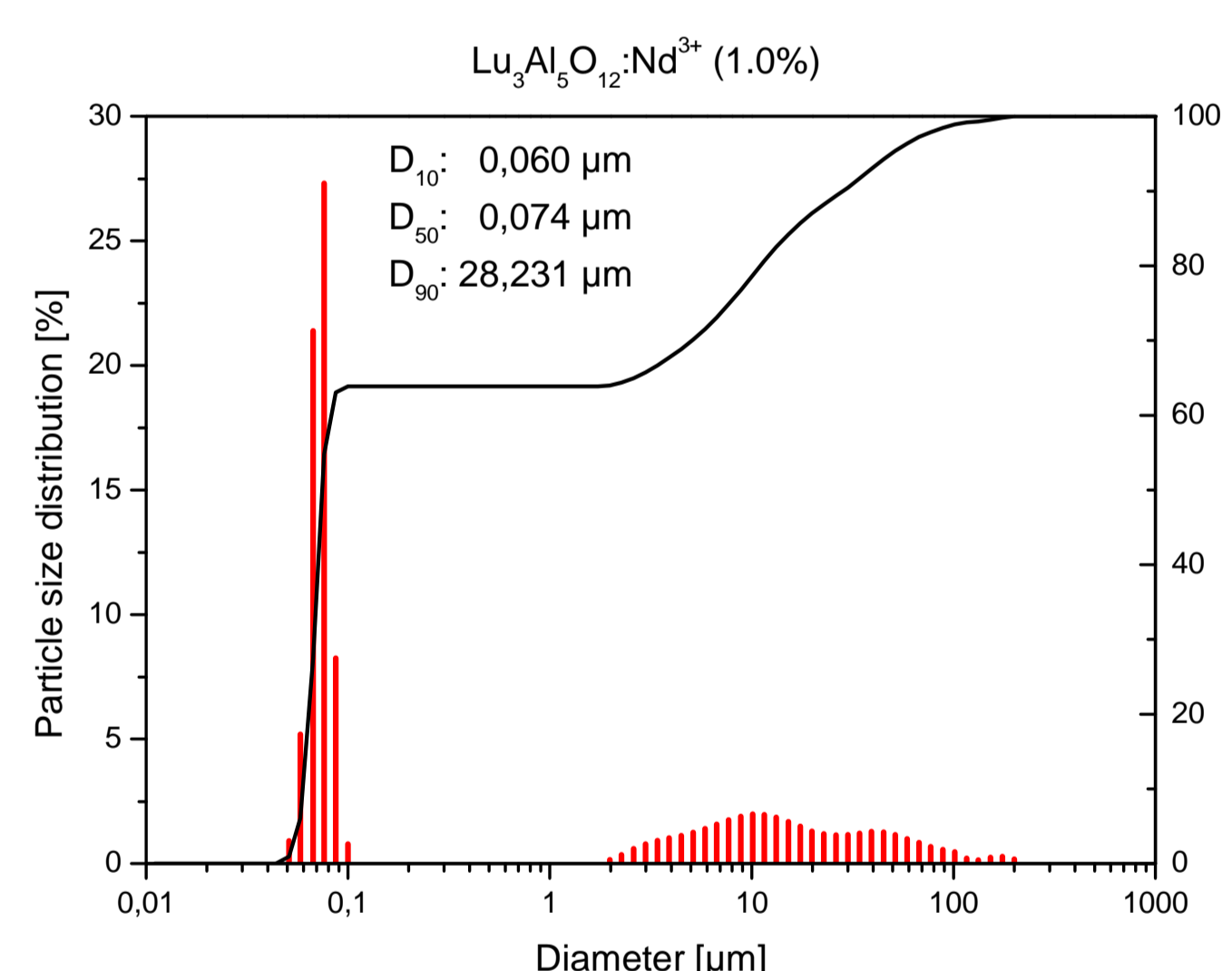


Fig. 6 Particle size distribution of autoclave powder sample

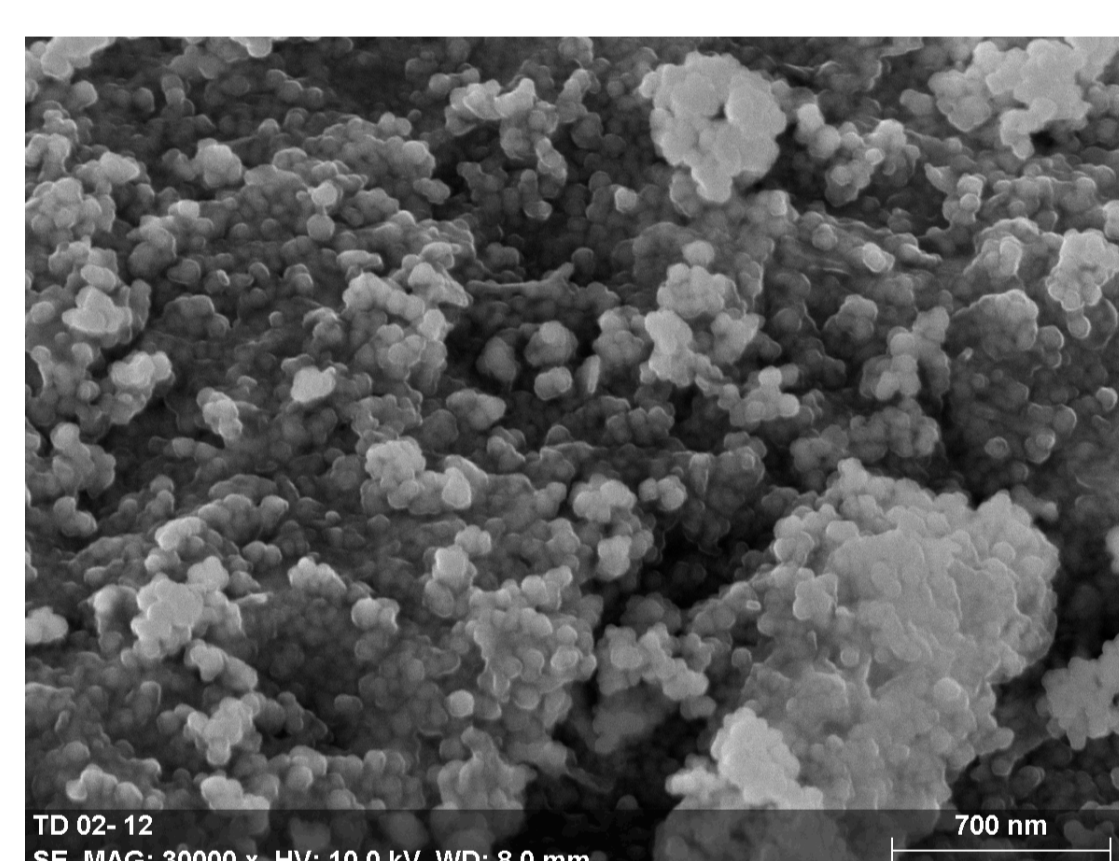


Fig. 7 SEM image of autoclave powder sample

Synthesis

Two fundamentally different synthesis routes were pursued in order to obtain suitable precursors for the manufacturing of green bodies.

The so-called combustion method uses Lu₂O₃, Al(NO₃)₃ and Nd₂O₃ as starting materials. All precursors were dissolved in diluted HNO₃, and the then clear solution was treated with tris(hydroxymethyl)aminomethane (Tris/THAM) before evaporated to dryness. The resulting foam-like matrix was pestled and heated at 1000 °C for 4 h. This route yielded single-phased LuAG with an average particle size of about 10 μm in diameter.

For the second synthesis route, viz. an autoclave reaction, Lu(Ac)₃, Nd(Ac)₃ and aluminium triisopropylate were used. The precursors were dispersed in 1,4-butanediol and heated in an autoclave at 300 °C for 2 h. The latter synthesis resulted in single-phased particles with an average diameter of 74 nm.

The individual green body precursors were initially pressed uniaxially and subsequently pressed isostatically. After sintering either method yielded, still phase pure, translucent ceramics, which were characterized by X-ray powder diffraction, SEM images, and particle size distribution measurements. Different pressure programs were applied in order to derive optimal green body fabrication conditions. However, all green bodies were sintered at 1700 °C for 4 h.

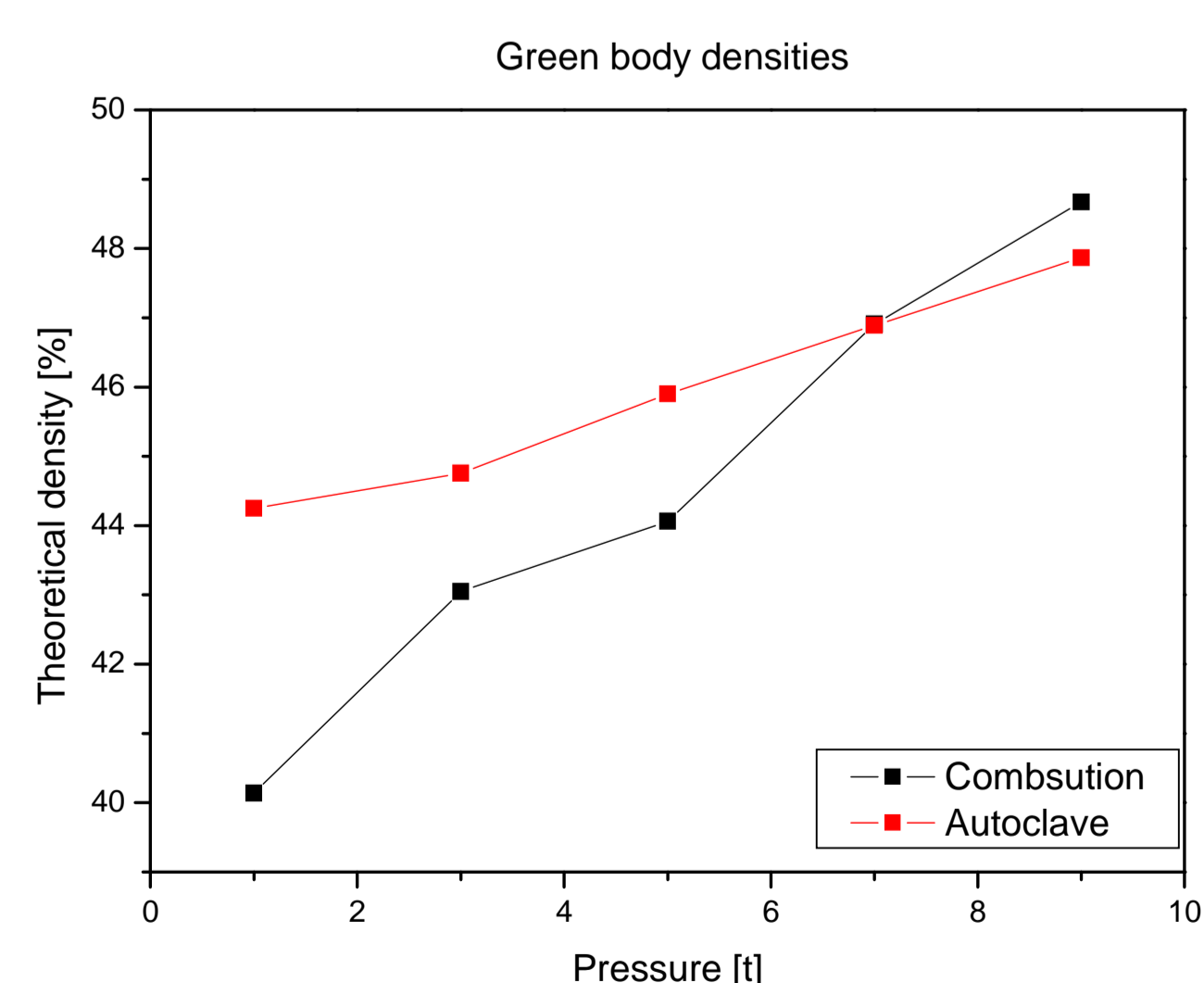


Fig. 8 Comparison of LuAG:Nd green body densities

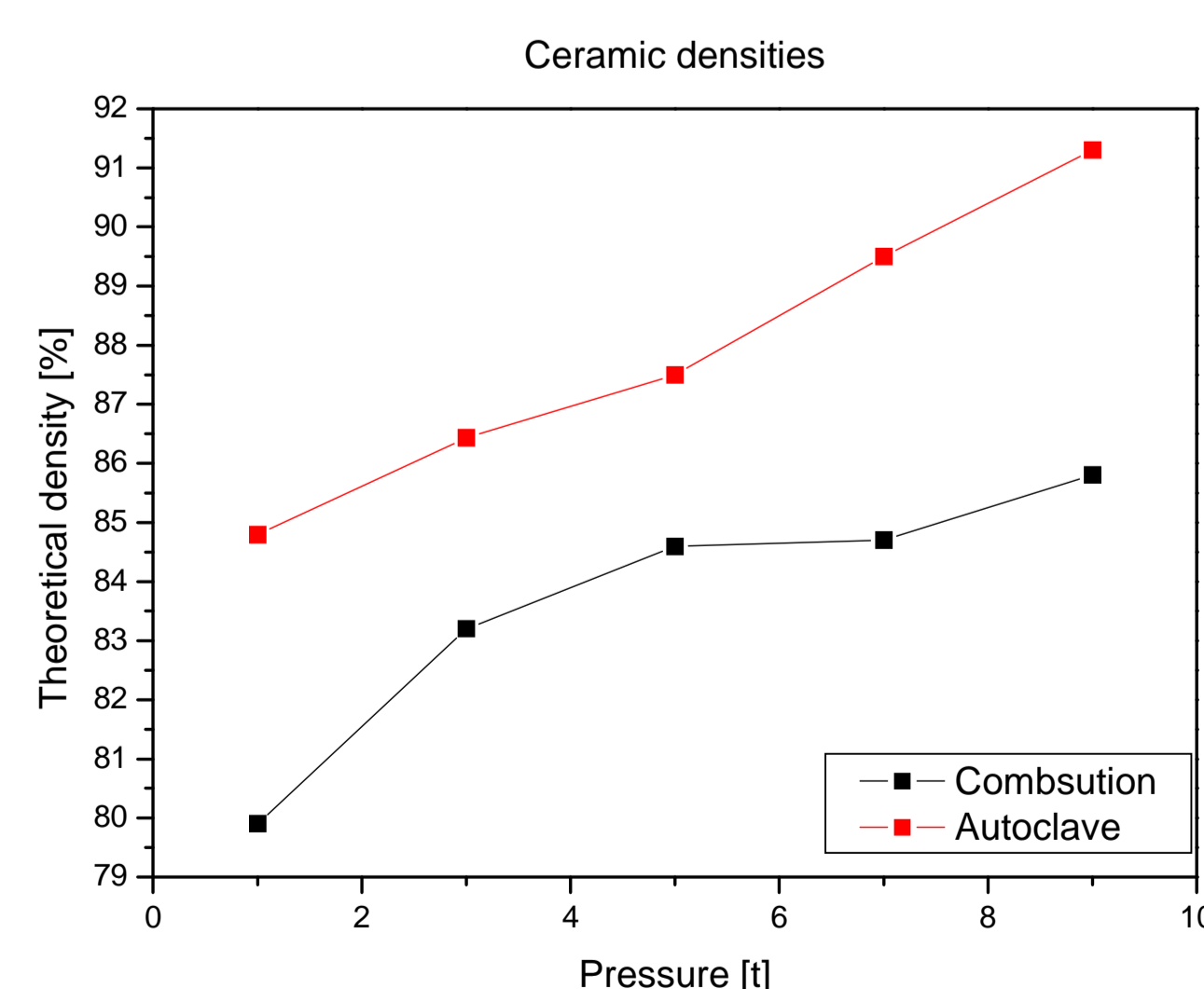


Fig. 8 Comparison of LuAG:Nd ceramic densities

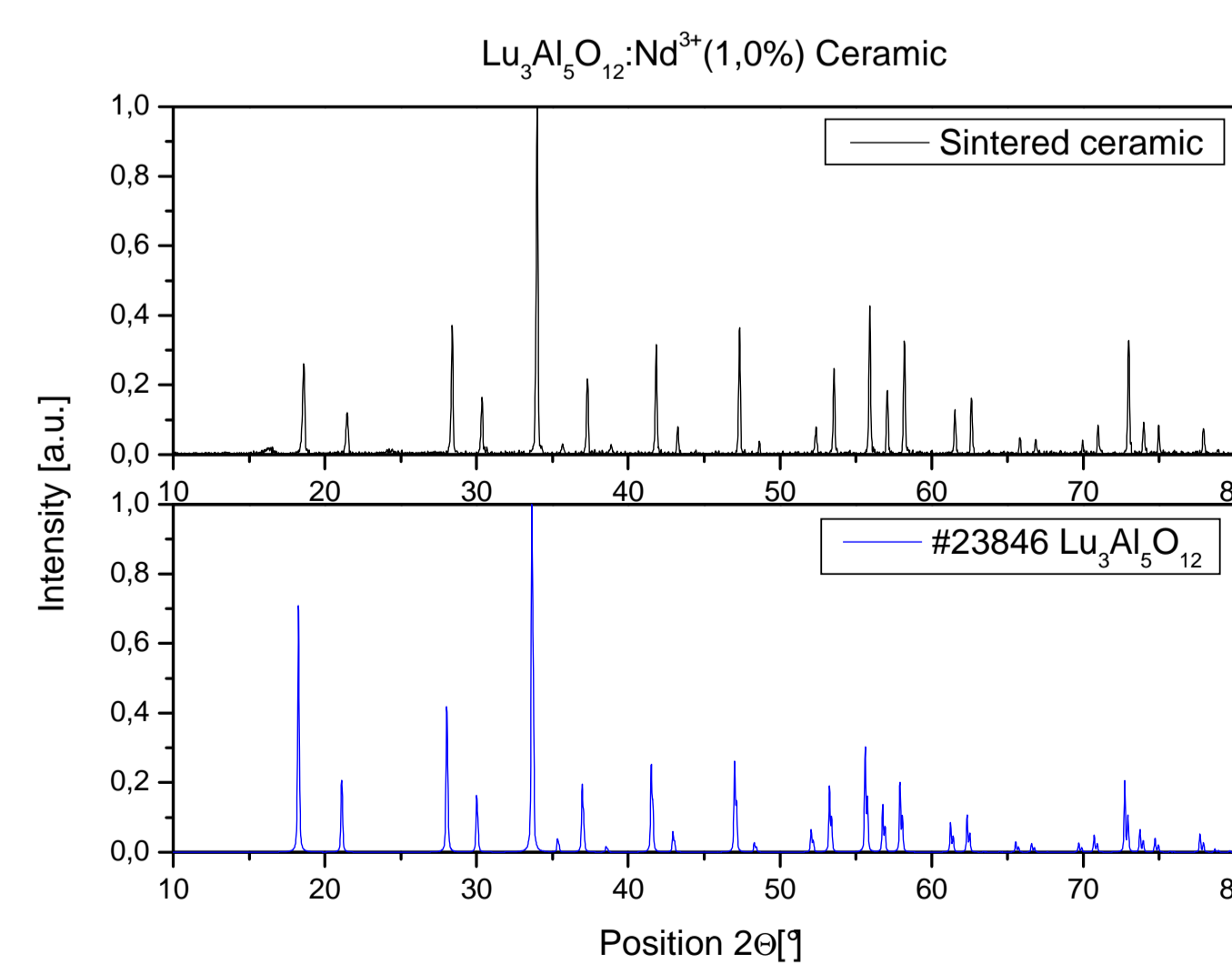


Fig. 9 Powder diffraction pattern of an as-prepared LuAG:Nd ceramic



Fig. 10 Translucent LuAG:Nd ceramic

Conclusions

In this study either synthesis resulted in green body densities up to almost 50% of the theoretical density and, in some cases, ceramics of well above 90% theoretical density. Although already translucent, the combination of the synthesised nano-scale LuAG with micro-scale particles is considered to be a promising way to obtain ceramics with even higher densities and thus improved optical features.