

# Thermal Laser Epitaxy of Oxides

## Ultrapure epitaxy beyond MBE and PLD

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In oxide epitaxy, MBE is generally regarded as the method producing the highest quality heterostructures. To address new opportunities in adsorption-limited deposition, however, higher substrate and source temperatures are required, together with higher active oxygen background pressures. We explore cw laser heating for both the substrate and individual elemental sources to overcome these limitations. In such a system, shown in Fig. 1(a), a long wavelength infrared laser is used to directly heat oxide substrates that are transparent to the radiation of standard heaters, allowing ultrahigh substrate temperatures above 2000 °C. Most elements in the periodic table are metals with melting points in or even above the range of fluxes required for deposition. Under these conditions, heating the central region of a source target by a laser produces temperature gradients large enough so that the target does not melt as a whole, as demonstrated for a 12 mm diameter Si source in Fig. 1(b). All these materials can therefore be evaporated without crucibles, by merely suspending them between three support points. Using a working distance of 60 mm, we achieve growth rates of more than 1 Å/s. We have experimentally verified such crucible-free evaporation (Fig. 1(b)) already for a majority of the non-radioactive elements in the periodic table (Fig. 1(d)).

We have achieved reliable deposition in up to  $10^{-2}$  hPa ozone/oxygen, such as the oxide layer shown in Fig. 1(c). As there are no hot filaments in the vacuum, both highly corrosive background gases and ultra-pure operation are possible. We obtain chamber pressures of  $6 \times 10^{-11}$  hPa at substrate temperatures of 1400 °C and  $2 \times 10^{-10}$  hPa during the deposition of Ru at a rate of 0.2 Å/s. The source targets are transferable in the same way as the substrates, allowing a flexible operation with different source materials in subsequent runs. The small source targets enable short working distances, allowing an efficient use of the source material, e.g. when working with isotope pure materials. The same scaling arguments as in MBE apply, permitting a straightforward upscaling of the epitaxy process to large substrate sizes. The process is agile, the substrate and the sources can be ramped at extreme rates due to their small heat capacity with direct heating and the absence of crucibles and the associated thermal expansion mismatch problems, thereby allowing high throughput volumes. And finally, the process chamber can be very small and simple, allowing both long uptimes and fast and easy rebuild or replacement in case of contamination or damage. First results on oxide epitaxy using TLE are presented and discussed.

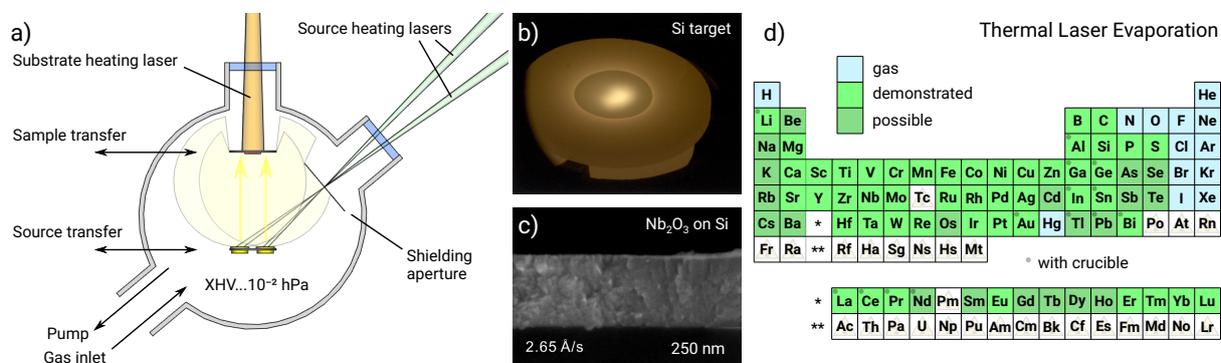


Figure 1: (a) Concept of thermal laser epitaxy. The yellow discs indicate the flux distributions of the source targets. Substrates and sources may be transferred into the chamber by the same mechanism. (b) Si target during evaporation. (c) Polycrystalline  $Nb_2O_3$  layer on a Si substrate. (d) Elements that can be deposited by thermal laser evaporation. Experimentally verified ones are marked in light green.