Staging superstructures in high-$T_c$ Sr/O co-doped La$_{2-x}$Sr$_x$CuO$_{4+y}$

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The very rich cuprate phase diagram continues to induce new investigations for the mechanism behind high-$T_c$ superconductivity in these materials. It is well known that the superconducting phase transition strongly depends on the hole content in the case of chemical substitution of La for Sr in La$_{2-x}$Sr$_x$CuO$_{4+y}$, as well as for intercalation of O in La$_2$CuO$_{4+y}$.

We will here present results of elastic hard X-ray scattering experiments on the Sr/O co-doped La$_{2-x}$Sr$_x$CuO$_{4+y}$ family of compounds, in particular with $x$=0.00, 0.04, 0.065, and 0.09. Co-doping by superoxygenating the Sr doped compound opens up for a vast space of new and surprising phases. In particular, these samples all have the same superconducting critical temperature $T_c=40$ K independent of the Sr content, in contrast to oxygen-stoichiometric samples. We observe the superstructure known as staging - or hints of it - in all four samples. Staging is characterised by a number $n$ referring to the periodicity of the intercalated oxygen layers in terms of CuO$_6$ spacings, and has only been investigated earlier in samples without Sr doping.

We find that the staging number $n$ increases monotonically with Sr doping $x$ despite the unchanged $T_c$. Furthermore, the transition temperature for the staging phase increases with $x$. This indicates a correlation between the randomly positioned Sr ions and the mobile oxygen interstitials, resulting in a stabilization of the staged phase with $x$, while the superconducting phase seemingly remains the same over varying $x$. This points to the interstitial oxygen that do not take part in the staging being responsible for the high-$T_c$ superconductivity in the samples.

**Keywords:** superconductivity, modulated crystal structure, staging, hard X-rays

![Figure 1](image_url)