

 T discovery of conductivity and magnetize and magnetize $\frac{1}{2}$ at the polar–nonpolar–nonpolar interfaces of insulating $\frac{1}{2}$ $n \rho \sqrt{2}$ and $\sqrt{2}$ and $\sqrt{2}$ and $\sqrt{2}$ and $\sqrt{2}$ and $\sqrt{2}$ and $\sqrt{2}$ $f(x) = \frac{f(x) - f(x)}{f(x)}$ in the microscopic materials. Yet, the microscopic origin of such microscopic origin of such as $f(x) = \frac{f(x) - f(x)}{f(x)}$ emergent phenomena remains unclear, posing obstacles to design of improved functionalities. \sim calculations of principles calculations of \sim La \sim \mathcal{L} is p_{max} and p_{max} and p_{max} \mathcal{L} (origin) p_{max} interfaces that the polar discontinuity across that p_{max} $m \times m$ dynamically the spontaneous formation of certain defects that in the polar field that in turn cancel the polar field $\frac{3}{2}$ \mathbf{r} induced by the polar discontinuity. The spontaneously formed surface on to interface conductivity, whereas the unionization $\frac{3}{2}$ is verified Ti-on-Allian the union $\frac{3}{2}$ \mathbb{R} antisite defects lead to interface magnetism. The proposed mechanism suggests proposed mechanism suggests practical mechanism supposed mechanism supposed mechanism supposed mechanism supposed mechanism supposed me α best principles for inducing and conductivity and magnetism at general magnetism at general magnetism at general magnetism at α $p \cdot p$ in the $p \cdot p$

having high ΔH at the interface or in the bulk. On the other hand, or in (ii) the concentration of interfacial defects must be minimized interfacial defects \hat{f} order to take advantage of (iii). In addition, (iii) since the 2DEG is α located at the conduction bands of the nonpolar material, it is advantageous to select the nonpolar material with low electron effective mass in order to achieve higher mobility.

Polar field compensation. Experimentally, only very weak \mathbf{P}_i residual field has been observed in the LaAlO film no matter whether its thickness is below or above the Lcc thickness is below ℓ ([refs 38–41,52\)](#page-7-0). This observation cannot be explained within the defect-free interface scenario, even including the ionic relaxations[53.](#page-8-0) In turn, whereas the V () model explains the we are electric field in LaAlO film above the LaAlO film above the LaAlO film above the LaAlO film above the L it below the Lc. This leads us to inspect the effects of all possible effects of all possible effects of all p cation antisite defects across the interface. Each individual interfacial antisite alone cannot cancel the polar field. [Figure 2ab](#page-2-0) shows that the LaSr, SrLa, TiAl and AlTi antisite defects have lower ΔH than other point defects (for point defects example, cation vacancies) in the layer where they are located. Therefore, the former are the dominant defects in their corresponding layers. The interfacial LaSr donor in the SrTiO side cannot set up an opposite dipole across the LaAlO film that can cancel the polar field inside the LaAlO film. Regarding the TiAl donor in the LaAlO side, the donor level is lower than the SrTiO conduction band at the interface. Therefore, the ionized electrons cannot be transferred to the latter so as to cancel the

spontaneously formed deep LaSr defects that have donor level higher than the VBM at the interface. Therefore, to induce interfacial hole conductivity, one should search for the polar– nonpolar interfaces where all such donors have high enough formation energy to form or (ii) their donor levels below the $V_{\rm eff}$, the interface distribution of the interface. Practically, the (ii) may be achieved more achieved more achieved more easily by searching for the polar material whose VBM is higher than the charge transition energy levels of those spontaneously formed interfacial donor defects.

The α interface magnetism. As α models[31–34](#page-7-0) that explain magnetism based on the intrinsic interfacial Ti ^þ ion in the SrTiO (that is, not a defect), we find below that the local magnetic moment originates from the $\frac{1}{\sqrt{2}}$

n-type interfaces, the AlO α -surface layer is dominated by T -surface layer is dominated by defects when ζ and by V defect when $\sum_{\beta\in\mathcal{S}}\zeta_{\beta}$ and \tilde{p}_∞ is dominated by the LaO-surface layer is dominated by SrLa and SrLa and SrLa and SrLa and La defects, respectively, below and above and above and \sim B4 units \sim Ti4 þ and Ti þ and Ti þ signals exist in both sides of the interface. The interface of the interface. The interface appearance of the Ti ^þ signals should not be taken as a sign of conductivity. Whether the Ti ^þ signals detected by photoemission below the Lc (refs 21,40,62,63) can be truly assigned to those Time the SrTiO side showledge s these TiAl local moments are ordered (ferromagnetic, or antiferromagnetic, or else) and whether and how they interact with the itineral decomposition of the itineral decompositions that should be should be should be should be sh investigated further.