Recent Applications of Landau-Ginzburg Theory to Ferroelectric Superlattices: A Review

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Abstract. This article briefly reviews recent developments of Landau-Ginzburg theory to ferroelectric phase transitions in superlattices. An overview of the contributions of Landau-type theory to study ferroelectric superlattices is given. Recent findings from first-principles calculations and experiments on intermixing, local polarization coupling and polar discontinuity at interfaces that are not address in these contributions are highlighted. This is followed by a review of recent developments of Landau-Ginzburg theory that addresses these emergent phenomena at interfaces, which is the focus of this review article. The Landau-Ginzburg approach to ferroelectric superlattices with spatial distribution of polarization is outlined. It describes the formation of intermixed layer with properties different from those of both layers. These intermixed layers are mutually coupled through the local polarization at interfaces. Polarization continuity or continuity at interfaces is determined by the nature of the intermixed layer formed at the interface region. Recent results obtained in investigating superlattices comprised primarily of ferroelectric and paraelectric materials are discussed. The results include modulated polarizations, phase transitions, dielectric susceptibilities and switching behaviors.

1. Introduction

Ferroelectric superlattices are currently a topic of active research [1-5] due to their potential applications [6, 7], as well as their striking new behaviors [8, 9]. Superlattices are considered as an alternative to ferroelectric thin films [10] because the alternating layers of different constituents allows tailoring of ferroelectric properties [11] for specific applications. Various techniques such as molecular-beam epitaxy (MBE) [12-14] and pulsed laser deposition (PLD) [15-17] have been used to fabricate high-quality epitaxial ferroelectric superlattices. The fabrication of superlattices has also been made through radio-frequency (RF) magnetron sputtering deposition [18-19]. Many superlattices have been fabricated and studied, including BaTiO$_3$/SrTiO$_3$ [12, 15, 20-28], PbTiO$_3$/SrTiO$_3$ [8, 11, 14, 29, 30], KTaO$_3$/KNbO$_3$ [31-33], SrTiO$_3$/BaTiO$_3$/CaTiO$_3$ [34, 35], as well as relaxor superlattices [36-41].

This review article is organized as follows: in Section 2, a complete overview on the theoretical works of ferroelectric superlattices based on the Landau theory and Landau-Ginzburg theory is presented. In Section 3, some emergent phenomena at interfaces such as intermixing, local polarization coupling and polar discontinuity at interfaces are discussed in relation to the theoretical works in Section 2. Recent development of Landau-Ginzburg theory that addresses these emergent phenomena at interfaces will be discussed in Section 4. It begins with an introduction to dipole lattices model of ferroelectric superlattices. The lattice model is then casted into a continuum Landau-Ginzburg theory form. In the continuum model, the interface parameter appears as an interface energy term in the free energy functional, which describes the formation of intermixed layer that are mutually coupled through the local polarization at interfaces. A number of recent results are discussed, including modulated polarizations, phase transitions, dielectric susceptibilities and switching behaviors. Finally, a summary is given in Section 5.