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Pu Zhang

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Symmetry and Degeneracy of Phonon Modes for Periodic Structures with Glide Symmetry

Pu Zhang[1]

Department of Mechanical Engineering, State University of New York at Binghamton, Binghamton, NY 13902, United States

Abstract: A large class of phononic crystals and mechanical metamaterials exhibit glide symmetry that dictates their functionality or exceptional performance. The glide symmetry gives rise to a number of intriguing phenomena like sticking-bands and degeneracy in the phononic band structures. Fully understanding of these phenomena demands analysis of the phonon modes' symmetry property, which is, however, a challenging task since it involves nonsymmorphic space group analysis and special treatment of the Brillouin zone boundary. Therefore, this work introduces a systematic group-theoretical procedure determining the symmetry of phonon modes for periodic structures with glide symmetry. By taking the *p*4*g* group as an example, the symmetry of phonon modes is discussed by deriving the small representations for high symmetry **k**-points, and different types of degeneracies are elucidated. This work provides insight into the role of glide symmetry on phononic band structures and guides the symmetry analysis of periodic structures of other types.

Keywords**:** Lattice structure, Glide symmetry, Phonon mode, Degeneracy, Group theory

1 Introduction

Recent progress on the design of structured materials mainly depends on special geometry to achieve desirable or exceptional functionality. A variety of novel structures and mechanisms have been summarized in some recent review articles (Bertoldi et al., 2017; Hussein et al., 2014; Lakes, 2017; Lee et al., 2012; Saxena et al., 2016; Yu et al., 2018; Zadpoor, 2016) and books (Laude, 2015; Phani and Hussein, 2017) regarding phonon crystals, mechanical/acoustic metamaterials, et al. In the literature, plenty of designs have involved structures with glide symmetry, either intentionally or not, that plays an essential role on their exceptional behaviors. Some of the representative structures with glide symmetry are illustrated in Figure 1. The first example is the hinged rotating squares (Figure 1a) with auxetic behavior (Grima et al., 2005; Grima and Evans, 2000). Normally the square patches are made of rigid materials. This structure has inspired a few similar designs, e.g. the fractal cut structures with supreme stretchability (Cho et al., 2014; Dudek et al., 2017; Tang et al., 2015) or controllable dynamic behaviors (Javid et al., 2016). The example shown in Figure 1b is obtained from the buckling pattern of an elastomer sheet with a square array of pores under biaxial compression (Bertoldi et al., 2008; Mullin et al.,

[1] Email: pzhang@binghamton.edu