I. INTRODUCTION

Many interesting phenomena have been observed in Bose gases with Feshbach resonances. Enormous particle-loss rate due to three-body recombination was found near the resonance [1]. Oscillations between atoms and diatomic Feshbach molecules were generated by a sudden change in magnetic field [2]. Large number of Feshbach molecules were produced from Bose gases either by tuning the magnetic field through the resonance [3] or by oscillating the magnetic field at a frequency corresponding to the molecular binding energy [4]. Even tetramer molecules were created from Feshbach molecules [5]. However BEC of Feshbach molecules in Bose gases has not been achieved in experiments so far and properties of this state are waiting to be explored.

Properties of atomic-BEC state have been extensively studied theoretically [6]. Phase transition between atomic and molecular BEC was proposed near the resonance [7–10]. However these phases suffer mechanical collapse in regions with negative scattering length $a_s < 0$ [11]. A recent work [12] shows that the molecular-BEC state of a Bose gas with a wide Feshbach resonance at zero temperature exists only when the atom density n satisfies $na_s^3 < 0.0164$ for positive scattering length $a_s > 0$.

In this paper, the molecular-BEC state of a homogeneous Bose gas with a wide Feshbach resonance is studied at finite temperatures. In the following, we first describe the molecular-BEC state in a mean-field approach where the Hatree-Fock energy and pairing gap are determined self-consistently. Long-wavelength excitations and molecular binding energy are obtained. Then mechanically stability of the molecular-BEC state is examined across the resonance, and the mean-field phase diagram is obtained. Coherent mixture of atomic and molecular BEC is also studied. Discussion and conclusion are given in the end.

II. MEAN-FIELD THEORY OF THE MOLECULAR-BEC STATE

A. Mean-field approach

In alkali-atom gases with Feshbach resonances, scattering states in the open channel and bound states in the closed channel are coupled together. Near a wide resonance, the effective range of the interaction is very small, and most atoms are in the open channel [13, 14]. A uniform Bose gas with a wide Feshbach resonance can be effectively described