Phase Separation Study Near the Tricritical Point in ^{3}He-^{4}He Mixtures

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Abstract

We are studying phase separation in ^{3}He-^{4}He mixtures using inter-digital capacitor (IDC) sensors located on the top of our cell. The IDC's measure the phase separation by probing the local concentration near each sensor. The IDC's were developed as part of our effort to eventually perform similar measurements on the International Space Station, in the absence of the stabilizing influence of gravity. The IDC's appear to be well suited for making measurements of the phase separation on both sides of the tricritical point, including on the ^{3}He rich side of the phase diagram where they observe the minority ^{4}He rich phase forming a macroscopic thick film at phase separation.

Key words: helium; mixtures; tricritical point

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1. Introduction

Our current understanding of critical phenomena can be uniquely tested at the tricritical point in the ^{3}He-^{4}He phase diagram[1] because tricritical points in 3 dimensions are one of the few physical systems for which Renormalization Group theory produces exact predictions. The associated critical exponents at a tricritical point are (exact) integer fractions with logarithmic corrections to this critical behavior. To fully test these exact predictions, the inhomogeneities introduced in the presence of gravity by the diverging concentration susceptibility must be removed.[2]

To study the tricritical point in the absence of gravity (like in the μ-g environment of the International Space Station), the phase separation process in the absence of gravity needs to be understood. On the ^{4}He-rich side of the phase diagram, where the ^{3}He molar concentration, X, is less than the tricritical concentration, X_{tcp}=0.675,[1] the minority phase will grow out of the ^{3}He enriched liquid-vapor interface.[3] Thus, a cell should have a vapor bubble volume outside the measurement volume to ensure the sample cell contains only the ^{4}He-rich component, enabling single phase measurements to be performed along the coexistence curve. On the ^{3}He-rich side of the phase diagram ($X > X_{tcp}$), phase separation will occur at the cell surfaces with the formation of a macroscopic ^{4}He-rich film,[4], [5] leaving the average concentration in the cell essentially unchanged. So, a sensor sensitive to the concentration near the cell walls would be necessary to observe phase separation on the ^{3}He rich side.

2. Technique

The Clausius-Mosotti function can be used to convert between a mixture's dielectric coefficient, ϵ (measured by a capacitor), and its density.[6] When a mixture is cooled to its phase separation temperature ($T_\sigma(X)$) a sharp kink in the dielectric constant will ap-

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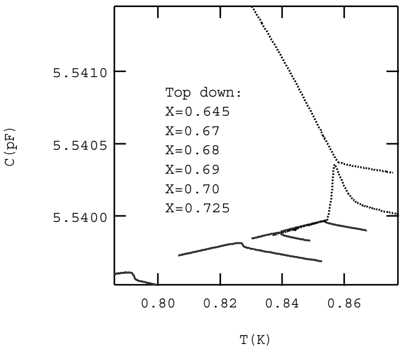

Fig. 1. Representative capacitance data taken with an IDC having 20μm fingers as a function of X and T.

pear as the mixture joins the coexistence curve. Each IDC consists of many equally spaced interpenetrating electrode fingers.[4] We manufactured IDC's of two different finger spacings (50μm wide and 20μm) on quartz substrates using standard thin film lithography. The substrate containing the IDC's was epoxied flush into the top of a 112μm tall pancake region in our cell to observe the formation of the ^{4}He rich film separate from the bulk separation for $X > X_{tcp}$.[4]

The capacitance of the IDCs were converted into the dielectric coefficient of the mixture by correcting for the quartz background (measured with the cell empty) and calibrating the sensors well above the coexistence curve at each concentration, where the mixture's dielectric coefficient is well known.[6]

3. Experimental Results

The capacitance of a 20μm IDC is shown in figure 1 as a function of temperature for 6 different average concentrations near X_{tcp}. The capacitance shows a signature at phase separation. Gravitational rounding is visible in the data ($X = 0.67$) taken closest to X_{tcp}. The $X = 0.67$ data also shows the ^{3}He rich minority phase entering the top of the pancake below T_σ.

The details of the phase separation become apparent in the helium dielectric coefficient data (see fig. 2). As T_σ is approached from the single phase region, a thin film rich in ^{4}He forms on the surface[5] for all concentrations. When $T_\sigma(X)$ is reached for $X < X_{tcp}$, the dielectric coefficient appears to follow the phase separation curve. In contrast, for $X > X_{tcp}$, a thick ^{4}He rich film forms (see Fig. 2).

Our preliminary numerical modeling of the IDCs to extract the film thickness from the observed changes in the dielectric coefficient indicates that the initial, thin film seen on both sides of X_{tcp} is a few 10's of nanometers thick, while the thicker film seen for $X > X_{tcp}$ is a few 100's of nanometers. The size of the thicker film seems comparable to films that form on a surface in the vapor above a mixture[7].

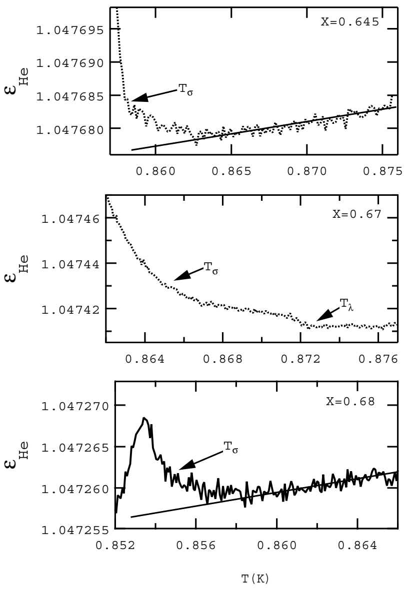

Fig. 2. Dielectric coefficient near phase separation showing the initial ^{4}He thin film growth prior to bulk phase separation (the deviation from the straight line). The superfluid transition, and gravitational rounding are visible in the X=0.67 data.

We plan to continue our study of phase separation by modifying our experimental cell to include IDCs at the bottom as well as the top.

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