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Effects of nanowire height on pool boiling performance of water on silicon chips

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ABSTRACT

A new technique is developed to directly grow Cu nanowire (CuNW) on Si substrate with electrochemical deposition to produce height-controlled hydrophilic nanowired surfaces for enhancing pool boiling performance. For broader heat transfer applications, CuNW and Si nanowires (SiNW) with various nanowire heights were fabricated and examined under pool boiling with water. The heat transfer performance of the samples with NW arrays is enhanced with increasing NW heights regardless of the NW materials. The surface with the tallest NW structure (35 μm-tall SiNW) yielded a heat flux of 134 W/cm^2 at 23 K wall superheat, about 300% higher than a plain Si surface at the same wall superheat.

1. Introduction

The generation of ultra-high heat flux from high performance electronic devices has motivated a number of investigations related to advanced heat transfer, especially in the area of pool and flow boiling performance. For most integrated circuit and logic chips, a cooling system is needed to maintain a relatively constant component temperature below 85 °C. Thus, primary issues related to the chip cooling with pool boiling are the enhancement of nucleate boiling, increasing the critical heat flux (CHF) and heat transfer coefficient (HTC).

Active studies have been conducted for several decades on enhancing the boiling heat transfer by surface modification. The recent surface treatment methods include increasing the surface area with micro pin-fins [1], applying wicking structures to promote the liquid supply by capillary pumping [2,3], and depositing nano-particles or coating with nanomaterials [4–6]. Among those developments, surface modification by incorporating nanomaterials and nanostructures has proven to be a promising technique for providing a more effective boiling heat transfer surface.

Table 1 gives a summary of recent studies that are related to the enhancement of boiling heat transfer by use of nanomaterials and nanostructures. Wu [7] reported a coating of hydrophilic titanium oxide nanoparticles on the heating surface that increased the critical heat flux (CHF) by 50.4% in pool boiling with FC-72.The enhancement is attributed to the hydrophilicity of the nanoporous layer. Chen et al [8]studied the boiling performance of a surface covered with super-hydrophilic titanium oxide nanotube array. The surfaces yielded approximately half the values of wall superheats during boiling at a given heat flux compared to the bare Ti surface. It is concluded that the nanotube array introduced a large number of active nucleation sites that promoted bubble generation. Carbon nanotube (CNT) is also studied for pool boiling applications [9–11]. The CNT coated surface is highly effective in improving both the CHF and HTC in the low heat flux region due to an increased surface cavity density and enhanced roughness. Significant enhancements in both the CHF and the HTC have also been obtained from surfaces coated with Cu nanorod and nanowire (NW) arrays [12–14]; the reported CHF (220 W/cm^2) for the CuNW surface is one of the highest for pool boiling heat transfer with water [14]. The nanowire structures are preferred in pool boiling enhancement due to their unique properties. The NWs enhance surface wettability, which helps in increasing CHF and delaying the dry-out condition [13]. Due to the pin fin effect, NW structures greatly increase the active heat transfer area. In addition, the NW height was found to directly affect the heat transfer [15]. By incorporating the hydrophilic NW structure with hydrophobic surfaces, the pool boiling performance can be further enhanced [16]. These studies have shown that most of the surface

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