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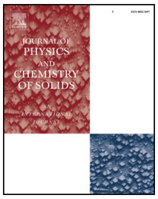

Al thin film: The effect of substrate type on Al film formation and morphology

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ABSTRACT

In this work aluminium (Al) films were deposited on different substrates, and their phase, microstructure and film growth process were tracked. Three types of substrates were explored to determine the influence of the substrate on the film growth process. It was determined that the growth mechanism of Al on the metal substrate was totally different from that on metalloids and glass. The Al film grown on metal substrate had a cross-grained structure, while films formed on glass had a fine-grained structure. Film grown on metalloids fell between the two. It was found that these differences in microstructure affected the film's optical properties. Films grown on silicon and glass were very reflective while film grown on the metallic substrate scattered light.

It was determined that nucleation of the film deposited on the metallic substrate began when the film thickness exceeded 50 nm. Further increasing thickness triggered grain growth, and the formation of crystallites up to 40 nm occurred when film thickness was 150 nm. It was observed that grain growth was more favorable on metallic substrates, and the lowest grain growth was observed on the glass substrate.

1. Introduction

Since the pioneering development of the first integrated circuit in the early 1960's [1], the density of devices that can be fabricated on a chip has increased incredibly. Aluminium (Al) is one of the most widely used interconnection materials because of its low resistivity and its good adhesion to SiO_2 and Si. In addition to outstanding electrical conductivity, which is close to the ideal bulk value [2], Al is low cost and highly stable, and as a result, aluminium thin films and Al alloys are widely used for electronic device applications [3,4].

Chemical vapour deposition (CVD) is one of the most highly developed methods for depositing Al thin films, and is widely employed because it provides satisfactorily uniform coverage and requires a relatively low process temperature. The main drawback of the approach is the high surface roughness of the deposited film when its thickness exceeds 20 μm. As an alternative to CVD, physical vapour deposition (PVD) techniques such as evaporation and sputtering are often used to deposit Al films. The main advantages of the PVD process are its high deposition rates and well-developed processing technology. Although present PVD methods usually involve high temperature steps during the deposition process, recently [5] low temperature deposition of Al film has been reported.

The physical properties of deposited Al thin films strongly depend on the film's microstructure [6–8]; this makes it possible to manipulate the film's properties by controlling its microstructure [9–11].

Although Al film is very attractive for electronic applications, it still has the very serious issue of surface roughness. Aluminium thin films begin to form hillocks at relatively low processing temperatures (i.e., above 300 °C) [12,13]. It has been reported that hillock formation strongly depends on thickness and temperature. In addition, the hillocks may cause shorts and the failure of devices. To avoid such catastrophic failures in electronic devices, hillock formation must be prevented. One of the common methods for preventing hillock formation is to add trace amounts of a second metal such as Cu or Nd to the Al matrix [14]. An alternative method is to sandwich the aluminium film between thin layers of other metals, such as titanium nitride, titanium, molybdenum, etc. [15]. In that process, the Al film is deposited directly onto a first layer and then covered with a capping layer.

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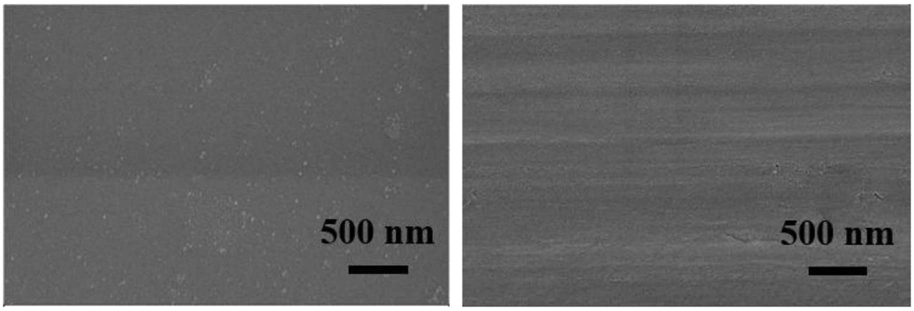
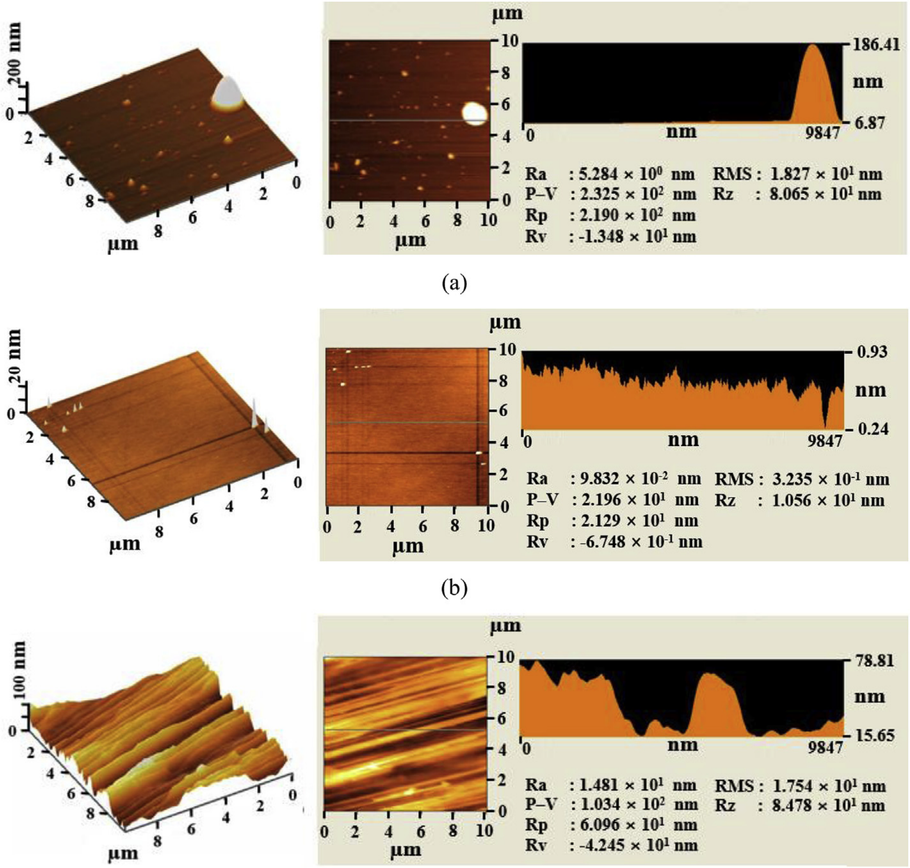


(a) (b)

Fig. 1. Morphologies of substrates' surfaces: SEM images of (a) glass and (b) steel.



(a)

(b)

(c)

Fig. 2. AFM images of (a) glass, (b) wafer, and (c) steel.

The next issue is related to interface stability. To improve contact between the silicon and aluminium the couple has to be annealed. However, at a certain temperature these two elements dissolve into each other and reach a eutectic formation point. This eutectic starts to form at about 450 °C, which is also the temperature required for good electrical contact. Therefore, annealing at this temperature forms an alloy which can extend through the junction and short it out. To solve this issue a barrier metal is used. In this approach the barrier metal is embedded between the aluminium and silicon to prevent the formation of the eutectic alloy. However, the deposited barrier metal becomes the new substrate, which may change the deposition physics. For instance, it has been reported that the quality of sputtered Al film strongly depends on the type of substrate and deposition temperature [16–18]. A higher deposition temperature strongly favoured smoother films [11].

As noted above, the substrate may have a certain influence on the formation and growth of Al films, and depending on the type of substrate and deposition conditions, the formed film may have a well-developed crystalline structure, or be amorphous. The microstructure is extremely important and determines the main properties of thin films including their electrical, mechanical, and optical characteristics.

In the semiconductor and display industries, aluminium thin films are commonly deposited on silicon (wafer), metal (e.g., on barrier metal), and on glasses. The deposition physics of each particular case are different and must be separately considered and optimized. In the frame of this study, the deposition of aluminium film onto these three different types of substrates is investigated.

The basic goal of this study was to estimate the influence of substrate type on Al film growth, and link crystalline structure to physical properties. Specifically, the effect of film thickness on grain size, degree of crystallization and surface roughness was examined for Al films