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Abstract—UV nanosecond pulsed laser annealing (UV NLA) enables both surface-localized heating and short timescale high temperature processing, which can be advantageous to reduce metal line resistance by enlarging metal grains in lines or in thin films, while maintaining the integrity and performance of surrounding structures. In this work UV NLA is applied on a typical Cu thin film, demonstrating a mean grain size of over 1 μm and 400 nm in a melt and sub-melt regime, respectively. Along with such grain enlargement, film resistivity is also reduced.

Keywords—laser anneal, BEOL, grain growth, copper.

I. INTRODUCTION

In advanced BEOL interconnects, reducing the trench geometry limits metal grain growth with the consequence of increasing electron scattering at grain boundaries. It results in an exponentially increasing line resistivity while scaling down the lines, and degradation of RC delay. In such scaling era, alternative metals such as Ru, Co, and Mo are introduced because of their potential benefits in line resistivity, which come from a complex combination of bulk resistivity, line width, mean-free-path of electrons, electro-migration reliability (i.e., melting point), integration compatibility, and especially the use of a specific set of barrier and liner [1-4]. However, even if the narrowest interconnects are formed with alternative metals, copper will not be completely replaced, and it will remain the reference to beat and the preferred candidate for larger interconnects. Thus, it is important to explore new paths to boost his performances and extend his utilization.

Extending Cu technology is still possible, especially by engineering the barrier/liner part [5-7]. On the other hand, nanosecond laser annealing (NLA) demonstrated a benefit on BEOL interconnects by enlarging the mean size of grains in both Cu [8,9] and Ru [10] lines. In fact, NLA allows to reach a much higher surface temperature than that of conventional BEOL limit (i.e., 400 °C for minutes), while conserving the functionality of surrounding devices thanks to its short timescale and shallow irradiation absorption. Such opportunity to reduce the interconnect resistance became particularly critical now, when the number of interconnect layers is continuously increasing [11].

In this paper we study high temperature processing realized by UV NLA to enable large-scale grain growth in thin films and lines (e.g., roughly 50-nm-thick). Specifically, we present the formation of large grains, which is, to our knowledge, a record for such a thin film (typically around 100 nm after annealing at 350 to 600 °C for minutes [12,13]). This opens a potential path to boost performances of future Cu interconnects.

II. EXPERIMENTAL

A 50-nm-thick sputtered-Cu was deposited on 8 nm-thick Ta/5 nm-thick TaN/100 nm-thick SiO2/Si without any capping layer on top. A UV NLA was performed at room temperature in air. Both laser fluence (LF) and process time (t) were varied to control the heat generated in the Cu film. The evolution of the material as a function of annealing condition was captured by in-plane XRD. Then, some selected conditions were analyzed by TEM and Electron Diffraction Mapping (EDM). Finally, the correlation between the film resistance and grain size was deduced.

III. RESULTS AND DISCUSSION

Figure 1 shows the XRD patterns taken at LF; for different t (t1 < t2 < t3 < t4 < t5), where the reference (i.e., non-annealed) data is also compared. In the as-deposited Cu film, the peaks of Cu (111), (200), and (220) planes are clearly observed, and a slight surface oxidation is also implied by the peak of Cu2O (111). For t1 and t2, the peaks of Cu (111) and (200) disappear, while those of Cu (220) grow. For t3, t4, and t5, the disappeared peaks emerge again, while the peaks of Cu (220) show a significant drop of intensity. This suggests that the Cu
the exponential growth of the metal resistance in advanced metal interconnects. In the sub-melt condition, the mean grain size (Av.) was increased up to 414 nm, almost 8-times-larger than that of the as-deposited film (Av. 53.9 nm), with a controlled distribution of grain orientations. In the melting condition, the grain growth was extended further (Av. 1000 nm), but the control of the grain orientation was not maintained. The observed grain growth led to a consistent reduction of the film resistivity. Although these results are promising, it is only the first fundamental study on thin films that motivates a further investigation. Particularly, the grain growth control needs to be confirmed in real interconnect structures. Also, it must be assured that the applied thermal budget does not degrade surrounding materials and structures.

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Fig. 1. XRD patterns obtained for the non-annealed and annealed Cu thin films. UV NLA was at $LF_1$ for different $t$ ($t_1 < t_2 < t_3 < t_4 < t_5$).

Fig. 2. Plain-view TEM images taken for the non-annealed and annealed Cu thin films. UV NLA was at $LF_1$ for $t_2$ and $t_4$.

Fig. 3. EDM images taken for the non-annealed (i.e., (a), (b), and (c)) and the annealed Cu thin films. UV NLA was at $LF_1$ for $t_2$ ((d), (e), and (f)) or $t_4$ ((g), (h), and (i)). As depicted in (j), ND, TD, and RD stand for Normal Direction, Transverse Direction, and Reference Direction, respectively. Also, a standard triangle of grain orientations is also shown in (k).

Fig. 4. Experimental and theoretical (based on the Mayadas-Shatzkes (MS) model) film resistivity of the non-annealed and annealed samples.