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Potential of air gap technology by selective ozone/TEOS deposition: Effects of air gap geometry on the dielectric constant

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Abstract

Air gaps offer an interesting alternative to low-k or ultra-low-k materials in order to reduce the line-to-line capacitance in a metallization system. A possible approach for air gap fabrication is based upon selective ozone/TEOS deposition. Feasibility of this method will be shown and capacitance reductions by almost 50% will be demonstrated. The potential for further reduction can be scanned by theoretical modelling of the line-to-line capacitance. The results indicate that effective k values below 2 are reachable by air gaps even if conventional materials like oxide and nitride are used in the process.

Keywords: Air gap; Ozone; TEOS; Simulation; Capacitance

1. Introduction

The decrease in feature sizes on integrated circuits has caused a growing importance of RC delays limiting circuit performance. The resistivity factor in the product RC has been reduced by the replacement of Al with the lower resistivity Cu as basic metallization material, and simultaneously the capacitance factor has been addressed by the introduction of low-k or ultra-low-k materials. The dielectric constant k of these materials is lower than that of the dielectric material of choice so far, SiO_2 with $k \approx 4$. These new materials, however, pose a series of problems for integration, such as mechanical and thermal stability issues, reliability degradation, or special requirements such as pore sealing, etc.

Air gaps may be a viable alternative to these materials. This term describes cavities between adjacent metal lines filled with air or gas, or being under vacuum. This is particularly attractive since air/gas/vacuum has the lowest permittivity of $k = 1$ among all "materials". In addition, air gaps

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can offer a scalable solution for multiple technology nodes. Of course, the overall, "effective" k value, in practice, is larger than 1 since the metal lines have to be supported by some material; but this holds true also for more conventional low-k or ultra-low-k approaches.

It is the intention of this paper to evaluate the potential of air gap technology based on well-known conventional materials in the dielectric system. It will be demonstrated that effective k values around or even below 2 can be achieved after careful design of geometries.

2. Air gap processing by selective ozone/TEOS deposition and electrical results

Air gaps have been fabricated in the literature by removing the dielectric material between the metal lines and closing the gap by a non-conformal oxide deposition process [1–3]. Because the growth direction of such a deposition process is mainly upwards, however, an elongated tip is formed at the top of the air gap before closure. This behaviour is not advantageous as it may result in the risk of re-opening the air gaps during CMP processing in case of varying line spacings or non-uniform CMP rates. An alternative approach is possible by a selective oxide deposition process, such as thermal decomposition of tetraethyloxysilane (TEOS) by ozone ("ozone/TEOS" [4]). In order to take advantage of the selectivity the dielectric material into which the Cu lines are embedded must consist of two layers; the materials of the bottom and top layers are selected such that ozone/TEOS grows on the upper layer only. Such a combination allows the air gap to close off after sufficiently long deposition. Because of the isotropic growth characteristics of ozone/TEOS the top part of the closed cavity is much smoother, and hence the above-mentioned integration issues are diminished.

A schematic process flow is depicted in Fig. 1. A slightly modified plasma-enhanced TEOS layer was selected for the "base" material for the dielectric stack since ozone/TEOS does not grow on its

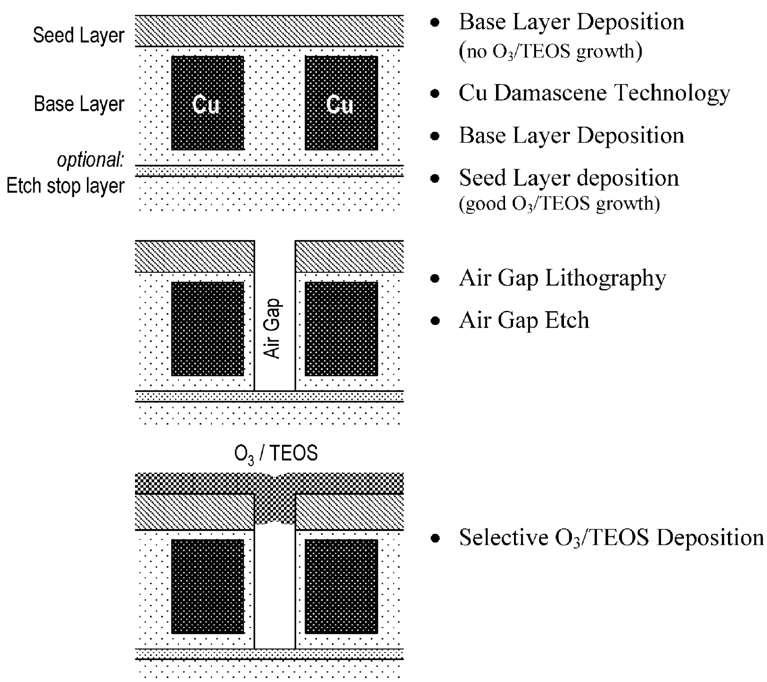

Fig. 1. Schematic process flow for fabrication of air gaps by selective ozone/TEOS deposition.