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High resolution fabrication of interconnection lines using picosecond laser and controlled deposition of gold nanoparticles

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Abstract

In this paper we present the fabrication procedure as well as the preliminary experimental results of a novel method for construction of high resolution nanometric interconnection lines. The fabrication procedure relies on a self-assembly process of gold nanoparticles at specific predetermined nanostructures. The nanostructures for the self-assembly process are based on the focused ion beam (FIB) or scanning electron beam (SEM) technology. The assembled nanoparticles are being illuminated using a picosecond laser with a wavelength of 532 nm. Different pulse energies have been investigated. The paper aimed at developing a novel and reliable process for fabrication of interconnection lines encompass three different disciplines, self-assembly of nanometric particles, optics and microelectronic.

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1. Introduction

Nanometric particles with different shapes and sizes have been one of the major scientific topics in the past few years due to their fascinating properties. Nanoparticles are widely employed in large variety and growing number of

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applications such as in biological field for bio-labelling (Ghosh et al. 2008, Sperling et al. 2008), heating (Cai et al. 2008) sensing (Lee and El-Sayed 2006) and medicine delivery (Salata 2004). In addition, nanoparticles are also being in-use, among other fields for applications of e.g. solar energy (Kamat 2007), in order to increase the energy going to the storage tanks as well as for the optical field for generating anti-reflective coatings. Those nanoparticles are being investigated in several research directions, starting from their fabrication process, analysis of their optical and electrical characterization and ending with their assembly process into their designated applicability. Nanoparticles may be of different shapes and sizes, such as nano discs (Maillard et al. 2003), stars (Nehl et al. 2006), triangles (Sherry et al. 2006) and nanorods (Jain et al. 2006). The optical properties of the nanoparticles strongly depend upon their size, shape, internal morphology and the dielectric constant of the surrounding medium (Shahmoon et al. 2011). It is also known that gold nanoparticles act as excellent absorbers and scatterers especially in the visible range since their plasmonic resonance is in this range when the nanoparticles have dimensions of few tens of nm.

Semiconductor microchips that lie at the heart of microelectronics are utilized in almost all electronic devices that are being in use today. The ongoing and rapid development of ultra large scale integration (ULSI) microchips, accompanied by a growing number of active elements, growth of operating frequencies, and continuous downscaling, urges the need to develop low cost and mass production compatible nano fabrication technologies.

We have been previously able to show that by performing a soft focus ion beam (FIB) processing of the surface of a silicon on isolator (SOI) wafer, then depositing charged gold nano particles on top of it and eventually washing the surface, causes to nanoparticles to remain only in the locations previously marked by the FIB (Shahmoon et al. 2010). This happens because the positively charged ions of the FIB are stuck in the oxide layer and apply electro-static attraction forces on the negatively charged gold nano particles.

Ultra-short laser pulses have been attracting major attention in the past few years due to their constantly decreasing cost and constantly increasing performance and thus they can recently be found in application such as material ablation (e.g. Tenner et al. 2013, used ultra-short laser pulses for ablation and welding and then tested the quality of the fusion state of the welded region using unique speckle based remote sensor).

In this paper we intend to use the self-assembly capability previously demonstrated by the group (Shahmoon et al. 2010) together with the usability of powerful pulsed laser in order to generate interconnections with nanometric resolution as thin as the size of the nanoparticles that are in use.

Thus, in this paper we present a new method for construction of downscaled high resolution nanometric interconnection lines. The suggested method enables realization of sophisticated nanostructure based on melting of self assembeled gold nanoparticles using a picosecond laser operating at a wavelength of 532 nm. The main advantage of this technology is by generating features which can be as small as the size of the nanoparticle itself (down to 2 nm), which is far beyond the capabilities of any photo lithography process. This high resolution is much better than the possible spatial width of the ultra-short laser pulse because in the proposed process the nanometric selectivity is obtained with the FIB (or the SEM) processing which position the nanoparticles in the right positions. Those tools have nanomatric precision and selectivity. The laser is only responsible to the melting of the nanoparticles. Thus, although the beam of the laser is much wider than the 2 nm particles, only one nanoparticle width is supposed to fall inside the scanning laser beam that is responsible for the melting.

The paper is constructed as follows: the assembly process of the nanoparticles into the desired structures is presented in Section 2. The preliminary experimental results are presented in Section 3, while the paper is concluded in Section 4.

2. Nanoparticles assembly

As previously mentioned, the proposed fabrication process involves marking the surface of the microelectronic wafer by FIB. The marking of the surface can also be done by an electronic beam (SEM). After the marking we place a suspension with charged metallic (gold) nanoparticles on top of the wafer. In the case of FIB, the positive ions of the FIB are implanted in the oxide below the silicon surface of the wafer and thus negatively charged nanoparticles from the suspension will stick to the positioned marked by the FIB (the desired conducting interconnection lines that are to be fabricated). In the case of SEM negatively charged electrons will stick below the surface of the wafer and thus positively charged metallic nanoparticles ought to be used. Again, due to the electrostatic force those nanoparticles will stick only to the locations marked by the SEM (the conducting interconnecting lines).