Al and Ga Nanoparticles Array Deposited on Silicon by UTAM for Sensors Applications

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Abstract. Highly order array of Al and Ga nanoparticles have been synthesized by controlling the size pores of Ultra Thin Alumina Membranes masks (UTAMs) produced by anodic alumina, the deposition of array was carried out on the silicon substrate, the roughness and the size distribution of Al and Ga nanoparticles has been investigated, also shown how to organize into order 3Dstructures. The AFM results show that the prepared films have nano dimensions, pores and have large surface area which increasing the probability of gas, chemical and/or photon interaction then they could be employed for sensing device fabrication.

1. Introduction

During the last fifteen years, metallic nanoparticles have attracted the attention of many researchers due to the double possibility of localizing light in nanometric dimension and getting high intensity local fields (excitation of localized Plasmon Resonances LPRs). Their use as plasmonic sensors has found many nanotechnology applications in biosensing nanocircuitry, spectroscopy, photovoltaic devices and microscopy[1,2]. Typical plasmonic sensor tools are made of Silver and Gold. Nanoparticles made of these metals show LPRs in the VIS-NIR range. Because of the enormous impact of these tools in biosensing applications and also because many biological molecules and matter respond in the UV part of the spectrum, it is necessary to investigate and design plasmonic tools able to work at shorter wavelengths[3,4]. Aluminum and Gallium have recently shown to be two possible candidates to cover this spectral rang. The purpose of this contribution is to show a numerical comparison through the DDA method (Discrete Dipole Approximation) between these metals and the conventional Gold and Silver when nanoparticles made of these material are located on dielectric substrate. The hemispherical particle shape will be taken as a basic geometrical model to develop this comparison, in part stimulated by the experiments performed [5,6].

Nanometer –sized particle are one of the main building blocks of nano devices. In the application of nano –particles as in the field of optical and electronic devices, it is usually desirable to fabricate ordered array of nanoparticles on substrates to improve the controllability and performance of the nano devices. The UTAM nanopatterning has been recognized as a suitable method for fabricating ordered nanoparticle array on substrates with controllable structural parameters and tunable properties [7].
2. Experimental Work

Template of Ultra Thin Alumina Membranes (UTAM) first prepared by anodization, it was made under a constant cell potential condition (voltage= 40 volt) in oxalic acid solution, after that several chemical procedures was carried out to obtain UTAM masks [8,9,10], Then Aluminum and Gallium nanoparticles produce by physical vapor deposition using an electron beam technique (EB), small pieces of (Al) and (Ga) have impurity about 99.999, put in graphite crucible after that put the substrate of Si with UTAM mask in the holder and centered above the crucible, then the deposition chamber was evacuated until reach 2×10^{-6} mbar ,next the deposition procedure was carried out by apply current until deposition rate become (0.1 Å/sec), after the deposition process was finished the samples were ready for synthesizing and characterizing measurements. Atomic Force Microscopic measurement, these measurements consist of several analysis use Gwyddion and imager 4.62 programs.

3. Results and Discussions

The atomic force microscope produces images for surfaces topography at very high magnification and it is even possible to observe the atomic structure of crystal. The aim of this study with the atomic force microscope is to obtain information about the surface formation, by analyzing the AFM images using the software “Gwyddion”. Line profiles and imager 4.62 were employed to estimate the Roughness, Length, height distribution, three dimension average height and average diameter of the Al and Ga nanoparticles.

The AFM images were shown in Figure (1) indicate that the particles cover the surface cavities, leading to decrease in the surface roughness; this may be due to two reasons. Firstly, using the UTAM masks [11]. Secondly, the lower rate of deposition [12].

![AFM images plane view of Al nanoparticles. a) Al nanoparticles at deposition rate of 0.1(Å/sec). b) Al nanoparticles at deposition rate of 0.2(Å/sec). c) Ga nanoparticles at deposition rate of 0.1(Å/sec).](image-url)
The size value distribution of Al and Ga nanoparticles are illustrate in Figure (2). While the length and 3D topography of Al and Ga nanoparticles shown in Figure (3).

Figure 2: On the left column the roughness of Al and Ga nanoparticles. On the right column high distribution a) Al nanoparticles at deposition rate of 0.1(A/sec). b) Al nanoparticles at deposition rate of 0.2(A/sec). c) Ga nanoparticles at deposition rate of 0.1(A/sec).
Figure 3: Length and 3D of Al and Ga nanoparticles. a) Al nanoparticles at deposition rate of 0.1\( (\text{A}^\circ/\text{sec}) \). b) Al nanoparticles at deposition rate of 0.2\( (\text{A}^\circ/\text{sec}) \). c) Ga nanoparticles at deposition rate of 0.1\( (\text{A}^\circ/\text{sec}) \).
Figure (4) shows the histogram of distribution density, the results show the particle density across the film, since large size particulates have the higher angular distribution, we have observed that a huge number of Al and Ga nanoparticles (right column). Left column shows the granularity cumulation distribution.

Figure 4: Histogram of the height and diameter is the function values distribution density. a) Al nanoparticles at deposition rate of 0.1(A°/sec). b) Al nanoparticles at deposition rate of 0.2(A°/sec). c) Ga nanoparticles at deposition rate of 0.1(A°/sec)
Table (1) illustrates the value of height particle for Al and Ga nanoparticle respectively. The table show the average value of heights are (92.648 and 91.878 nm) for Al nanoparticles at deposition rates (0.1 and 0.2 Å/sec) respectively and (92.739 nm) for Ga nanoparticles at deposition rate (0.1 Å/sec).

Table 1: Height Cumulation Distribution | a) Al nanoparticles at deposition rate of 0.1(Å/sec). | b) Al nanoparticles at deposition rate of 0.2(Å/sec). | c) Ga nanoparticles at deposition rate of 0.1(Å/sec).

| a | Avg. Height:92.648 nm | <=10% Height:0 nm | <=50% Height:90.0000 nm | <=90% Height:95.0000 nm |
|---|---|---|---|---|
| Height(n m)< | Volume (%) | Cumulatio n(%) | Height(n m)< | Volume (%) | Cumulatio n(%) | Height(n m)< | Volume (%) | Cumulatio n(%) |
| 80.0000 | 10.14 | 10.14 | 90.0000 | 2.90 | 24.64 | 100.000 | 37.68 | 97.83 |
| 85.0000 | 11.59 | 21.74 | 95.0000 | 35.51 | 60.14 | 105.000 | 2.17 | 100.00 |

| b | Avg. Height:91.878 nm | <=10% Height:80.0000 nm | <=50% Height:90.0000 nm | <=90% Height:95.0000 nm |
|---|---|---|---|---|
| Height(n m)< | Volume (%) | Cumulatio n(%) | Height(n m)< | Volume (%) | Cumulatio n(%) | Height(n m)< | Volume (%) | Cumulatio n(%) |
| 80.0000 | 7.89 | 7.89 | 90.0000 | 15.79 | 34.21 | 100.000 | 47.37 | 100.00 |
| 85.0000 | 10.53 | 18.42 | 95.0000 | 18.42 | 52.63 | 100.000 | 100.00 |

| c | Avg. Height:92.739 nm | <=10% Height:80.0000 nm | <=50% Height:90.0000 nm | <=90% Height:95.0000 nm |
|---|---|---|---|---|
| Height(n m)< | Volume (%) | Cumulatio n(%) | Height(n m)< | Volume (%) | Cumulatio n(%) | Height(n m)< | Volume (%) | Cumulatio n(%) |
| 80.0000 | 2.86 | 2.86 | 90.0000 | 14.29 | 31.43 | 100.000 | 48.57 | 100.00 |
| 85.0000 | 14.29 | 17.14 | 95.0000 | 20.00 | 51.43 | 100.000 | 100.00 |
4. Conclusion

From our results, we can conclude that the Al and Ga nano particles deposited on the silicon substrate to form nano structural thin films by using a simple physical deposition method. The AFM morphological studies show that the prepared films have large surface area, increasing the probability of interaction with the film materials (as chemical, gas or photon).

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