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Deposition of aluminium nanoparticles using dense plasma focus device

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Abstract. Plasma route to nanofabrication has drawn much attention recently. The dense plasma focus (DPF) device is used for depositing aluminium nanoparticles on n-type Si (111) wafer. The plasma chamber is filled with argon gas and evacuated at a pressure of 80 Pa. The substrate is placed at distances 4.0 cm, 5.0 cm and 6.0 cm from the top of the central anode. The aluminium is deposited on Si wafer at room temperature with two focused DPF shots. The deposits on the substrate are examined for their morphological properties using atomic force microscopy (AFM). The AFM images have shown the formation of aluminium nanoparticles. From the AFM images, it is found that the size of aluminium nanoparticles increases with increase in distance between the top of anode and the substrate for same number of DPF shots.

1. Introduction
Aluminium is an important material for making contacts in silicon technology for its ability to make both ohmic and Schottky contacts [1]. It is possible to make ohmic contact by making the metal contacts to p-type regions and heavily doped n-type silicon regions and rectifying contact to lightly doped n-type silicon regions. The need for low temperature processing and low resistive material in IC technology has made this simple metal contacts widely used in large scale integration (LSI) and also in early stage of the very large scale integration (VLSI) in recent times. Nanostructures like aluminium silicon nanowire networks have also been fabricated on glass and Si substrates by dealloying an Al-Si thin film through selective chemical etching [2] in order to miniaturize and make power efficient devices. Nanowire can act as electron confinement structure. When it is coupled with appropriate self configuring computer control architecture it would enable realization of self assembled ultrahigh density electronic device. So, metallic contacts of atomic dimensions have been a subject of interest in recent times. Plasma aided nanofabrication [3-6] has been considered widely for material deposition. Many techniques such as ionized cluster beam (ICB), partially ionized beam (PIB) [7], electron beam evaporation [8], magnetron sputtering [9], pulsed microarc discharge [10] techniques have been employed to deposit aluminium on different substrates. ICB technique has a limitation that the requirement of using a small nozzle of the order of 1-2 mm for supersonic
expansion of the vapor lowers the deposition rate. These techniques make use of ion beam which are less fluence and less energetic to deposit materials.

Recently, strongly non equilibrium plasma of high density and high temperature has been used for nanofabrication [3-6]. We have made use of Dense Plasma Focus (DPF) device [11-12] to create high density (~10^{26} m^{-3}) and high temperature (~1-2 keV) plasma which fully ionizes the material placed on the top of the modified anode. This device is low cost and is able to deposit wide range of materials on different substrates at room temperature. It has been used in earlier research works for introducing phase change in materials [13-17] and for preparation of thin films [18-21]. More recently, the DPF device is used for deposition of nanoparticles of different materials [3-4]. In the present work, we have deposited aluminium nanoparticles on n-Si (111) substrate using this device. The distance between the top of anode and substrate is kept at 4.0 cm, 5.0 cm and 6.0 cm so as to get uniform deposition without damaging the substrate. The deposited nanoparticles are characterized using Digital Instrument CP-II Scanning Probe microscope for their morphological properties. The Atomic Force Microscope (AFM) images for the Al nanoparticles have been taken in the non-contact mode.

2. Experimental set up
The DPF device shown in figure 1 is of Mather type with 3.3 kJ energy powered by a 30μF, 15kV fast discharging energy storage Maxwell capacitor. The hollow anode has a cylindrical detachable top in which the aluminium material of 99.999% purity is fitted in the form of a disc. The plasma chamber is evacuated and then filled with argon gas to a pressure of about 80 Pa. The construction and working of DPF [11-12] in details can be found in earlier research papers. The substrate on which the film is to be deposited is mounted on a perspex substrate holder and is inserted from the top of the focus chamber using a movable brass rod. The distance between the top of the anode and the substrate can be varied by moving the brass rod along the axis of the anode. A shutter is introduced between the anode and the substrate in order to prevent ions reaching the substrate due to unfocussed plasma. Good focussing is indicated by a sharp peak in the voltage probe signal which is recorded on a Digital Storage Oscilloscope (Tektronix TDS 784). The shutter is removed after good focussing is obtained. In the present work, we are using DPF device to deposit Al nanoparticles on Si substrates for two focused DPF shots.

3. Results and discussions
The XRD pattern of deposited material on n-Si substrate placed at 5.0 cm from top of the anode with eight DPF shots recorded with a powder diffractometer using CuKα shows a diffraction peak at

![Figure 1. Modified Dense Plasma Focus Device:](image)
$2\theta = 44.8^\circ$ which corresponds to the (200) plane of aluminium [22]. This confirms the presence of Al only.

The surface morphology of the Al nanoparticles is investigated using an AFM. AFM images of Al nanoparticles deposited on n-type Si substrate placed at a distance of 4.0 cm, 5.0 cm and 6.0 cm from the top of the anode with two DPF shots are shown in figures 2, figure 3 and figure 4 respectively. The critical dimension analysis of the AFM images enables us to obtain the average dimension like radius of the Al nanoparticles. The area analysis of the AFM images gives average height of a selected portion of the image and also for the whole scan area. Since the scan area of the AFM images in figure 1, figure 2 and figure 3 are not same, we select an area equal to 1μm X 1μm of AFM images of Al nanoparticles for the average height measurement. The range of the diameter of nanoparticles from critical dimension analysis and average height from area analysis of AFM images are listed in table 1. The size of nanoparticles deposited with two DPF shots is found to increase with increase in the distance between the top of the anode and the substrate. The increase in the size of the aluminium nanoparticle may be attributed to the agglomeration of the Al nanoparticles taking place while they are moving towards the substrate. The agglomeration of Al nanoparticles seems to increase with the increase in the distance between the anode and the substrate. Thus, smaller size of nanoparticles can be
Table 1. Diameter and average height of Al nanoparticles deposited on Si substrate

| Diameter (nm) | (a) 4.0 cm | (b) 5.0 cm | (c) 6.0 cm |
|--------------|------------|------------|------------|
| Average height (nm) | 30 - 70    | 70 - 170   | 100 - 200  |
|                | 29         | 19         | 17         |

obtained at lesser distance. It may be noted that the substrate gets damaged at a separation lesser than 4 cm.

The formation of aluminium nanoparticles using DPF device may be understood in the following manner. The aluminium disc on top of the central anode is brought into ionized state by high temperature plasma. These fully ionized aluminium ions along with argon ions move vertically upwards in a fountain like structure and lose its energy to ultimately deposit on the substrate as Al nanoparticles. The number of nucleating Al particles reaching the substrate is not uniform. In addition, the lattice mismatch between nucleating Al particles and substrate provides the preferential sites for heterogeneous nucleation. As such growth and nucleation in DPF device is heterogeneous.

4. Conclusion
The result of XRD and AFM images establish conclusively that aluminium nanoparticles can be deposited on n-type Si under extreme non-equilibrium plasma conditions such as available from DPF device. The surface morphological analysis using AFM of the deposited nanoparticles shows that the size of nanoparticles is found to increase with distance between the top of central anode and the substrate. These nanoparticles will find applications in making contacts on VLSI circuits in addition to many other applications.

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