Controlled Assembly of Sb, Bi and Ag Clusters on Insulating Substrates

J.G. Partridge[a,b], S.A. Brown[a,b], A.D.F. Dunbar[a,b], R. Reichel[a,b], M. Kaufmann[a,b], M. Schulze[a,b], S. Scott[a,b], C. Siegert[a,b] and R. J. Blaikie[a,c]

[a] *Nanostructure Engineering Science and Technology (NEST) Group and the MacDiarmid Institute of Advanced Materials and Nanotechnology*

[b] *Department of Physics and Astronomy, University of Canterbury, New Zealand.*

[c] *Department of Electrical and Computer Engineering , University of Canterbury, New Zealand.*

Two approaches to fabricating nano-scale structures on microelectronics friendly substrates which both use metallic clusters as building blocks are presented. Firstly, percolation theory is used to describe the deposition of a random percolation network of conducting clusters. This allows the design of a contact arrangement which results in short cluster chains between the electrical contacts. Secondly, substrates pre-patterned with V-grooves are used to cause clusters to aggregate (at the apex of the V-groove) into nanowires.

1. Introduction

Atomic clusters are known to possess a range of interesting properties [1,2,3], which gives them the potential to be used to develop a whole range of novel materials for the electronics and photonics industries. The ultimate target for such industries is to be able to manipulate individual atoms to fabricate devices; however this is not a simple task. By using clusters of atoms to build device structures it is possible to bridge the gap between processing bulk material, as occurs in today's industrial processes, and manipulation of individual atoms.

In this report, we describe briefly the method we use to produce the clusters and then go on to outline two different approaches to production of cluster assembled devices. Cluster deposition onto passivated silicon substrates is used to achieve ready-contacted nano-scale structures.

2. Cluster production

Clusters are produced by heating a crucible filled with the appropriate metal in an aggregation chamber (Sb : ~760°C, Bi : ~850°C, Ag : ~1200°C). The metal vapor thus produced is cooled by injecting a controlled amount of inert gas (Ar) into the chamber (~2 Torr). Cooling the vapor causes the aggregation of metallic atoms to form clusters. Both the inert gas and clusters are then sucked out of the chamber through a series of axially aligned apertures, separated by three stages of vacuum pumping, each stage decreasing in pressure from the previous. The lighter inert gas is largely drawn away by the pumps, leaving a collimated beam of clusters which enters a deposition chamber at a base pressure of ~2×10^{-6} Torr. A nominal cluster deposition rate is determined using a quartz crystal film thickness monitor and deposition on to the substrates is controlled by a mechanical shutter.

3. Comparison of clusters by SEM

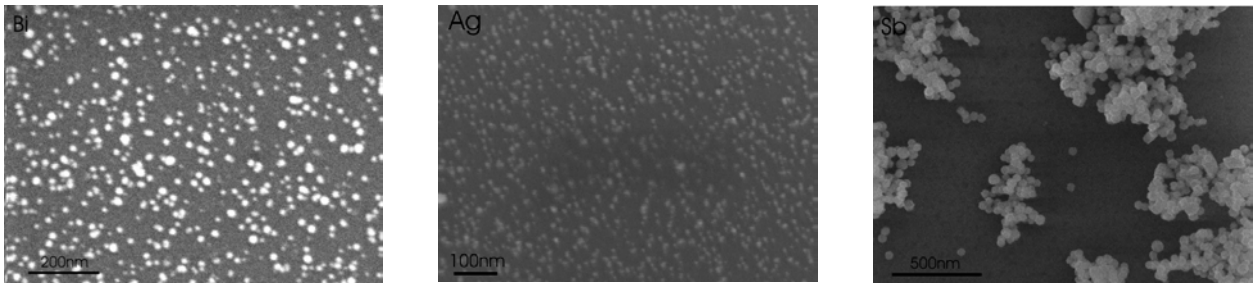

Fig. 1. SEM images of Bi (left) Ag (middle) and Sb (right) clusters deposited on to silicon oxide substrates.

As shown in Fig. 1 the average cluster size for the Bi, Ag and Sb clusters are ~20nm, ~15nm and ~40nm respectively. Both the Ag and Sb clusters retain their spherical shape after deposition onto the substrate, whereas the Bi clusters tend to take on a flattened dome shape. The Bi and Ag clusters stick to the substrate in a random distribution, whereas the Sb clusters tend to bounce off the substrate, only sticking if they impact upon another Sb cluster or other suitable sticking site. Therefore the Sb clusters do not have a random distribution on the substrate, but adhere to the substrate in large groups of clusters.

4. Percolation theory applied to conduction in randomly distributed cluster films

Percolation theory can be used to describe conduction through percolating networks of randomly distributed metallic clusters [4,5]. By reducing the contact separation between the pre-defined electrical contacts the number of clusters required to span the gap between the contacts is reduced. If the length of the contacts is also increased the probability that the first conducting connection between the contacts is an approximately straight chain of clusters is greatly increased. These two requirements are easily achieved by using an inter-digitated finger geometry for the electrical contacts. Therefore a chain of clusters resembling a nanowire can be fabricated. This method however is limited to nanowires of ~5 cluster diameters in length; otherwise a complicated network of clusters forms rather than a single nanowire. Research in this area is ongoing to realize and characterize such nanowires.

5. Cluster deposition on to V-grooved substrates

Deposition of clusters onto insulating substrates pre-patterned with V-grooves and with electrical contacts defined at either end of the V-grooves results in the production of cluster nanowires. The length of the nanowires is restricted only by the separation of the pre-defined contacts and the cluster beam diameter (typically ~3mm). One potential complication in the production of nanowires by this method is the occurrence of percolating conduction pathways on the plateaus either side of the V-groove. This problem can occur when using large amounts of Bi and Ag clusters to form wires, however careful deposition of smaller amounts of Bi and Ag clusters result in the production of aggregated cluster wires in the V-grooves without alternative conduction pathways on the plateaus. By using Sb clusters this problem is avoided because they tend to bounce off the substrate unless they impact upon another Sb cluster or sticking site. Sb clusters readily stick to the apex of the V-groove but seldom stick to the flat plateaus, see Fig. 2. This effect is enhanced if the cluster source pressure is increased which results in a higher velocity cluster beam [6]. Therefore it is possible to make Sb cluster assembled nanowires exceeding 1mm in length and ~100nm in width.

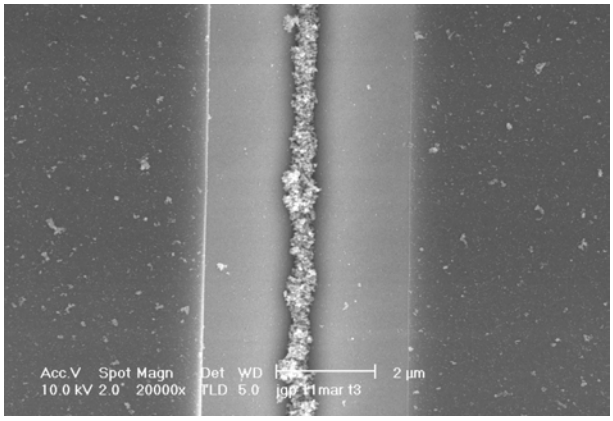

Fig. 2. A nanowire formed by depositing Sb clusters at high velocity onto a V-grooved Si substrate (with an insulating oxide layer to isolate the nanowire)

6. Conclusions

Both bismuth and silver clusters adhere to the insulating substrate surfaces in a random distribution and therefore percolation theory can be successfully applied to these materials, unlike the case for the antimony clusters where percolation theory cannot be successfully applied since they do not adhere to the surface in a random distribution [5]. The application of percolation theory allows the production of short approximately straight chains of clusters aligned such that they form a nanowire, and also larger percolating networks of many entangled nanowires.

The tendency of Sb clusters to bounce off the substrate surface unless they impact upon another Sb cluster or suitable sticking site has been utilized to produce long nanowires of Sb clusters at the apex of V-grooves. Bi and Ag wires have also been produced by this technique.

Both these methods produce ready-contacted nanowires and therefore allow in situ electrical characterization of the nanowires to be performed.

Acknowledgments

The help of the clean room staff of the electrical and computer engineering department and the technical workshop staff of the physics and astronomy department (University of Canterbury) are gratefully acknowledged.

References

[1] R. Busani, M. Folkers, and O. Cheshnovsky, *Phys. Rev. Lett.* **81** 3836 (1998)

[2] S. L. Lai, J. Y. Guo, V. Petrova, G. Ramanath, and L. H. Allen, *Phys. Rev. Lett.* **77** 99 (1996)

[3] K. Meiwes-Broer, *Metal Clusters at Surfaces* (Springer, Berlin, 2000)

[4] J. Schmelzer Jr., S. A. Brown, A. Wurl, and M. Hyslop, *Phys. Rev. Lett.* **88** 226802-1 (2002)

[5] A. D. F. Dunbar, J. G. Partridge, M. Schulze, and S. A. Brown, submitted to *Phys. Rev. B* (2004)

[6] J. G. Partridge, S. Scott, A. D. F. Dunbar, M. Schulze, S. A. Brown, A. Wurl, and R. J. Blaikie, To be published in *IEEE Trans. Nanotech.* (2004)