Vacuum 114 (2015) 124–129

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Extended-area deposition of homogeneously sized nanoparticles using modified inert gas condensation technique

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ARTICLE INFO

Article history:
Received 2 September 2014
Received in revised form
19 January 2015
Accepted 20 January 2015
Available online 31 January 2015

Keywords:
Inert gas condensation
Sputtering
Wide-area deposition
Homogeneous nanoparticles

ABSTRACT

The inert gas condensation (IGC) process was modified to synthesize and directly deposit thin films of homogeneously sized NanoParticles (NPs) over a large surface area. We replaced the single 2 mm hole that is used to extract the nanoparticle beam with a multiple-hole pattern consisting of 25 holes, each 0.31 mm in diameter, arranged as a 5 × 5 array. The resultant deposition covered a larger substrate area of 144 mm^2 but the NPs were deposited only on the substrate area in front of the holes, leaving the rest of the area devoid of NPs. Thus in order to achieve deposition over the entire substrate area a single slit gasket was used and the substrate was continuously rotated during the synthesis process using an 8 rpm motor. The slit used was 20 mm long and 0.13 mm wide. A deposition over the entire substrate area of 350 mm^2 was achieved using this single slit IGC. Homogeneous NPs of Copper, Silver, Indium Nitride and Aluminum Nitride doped with Erbium, were deposited over (111) p-type Silicon wafer. Field emission scanning electron microscopy study demonstrated uniformity in the size of these NPs. Thus NP deposition area was increased from 1–2 mm^2 to 350 mm^2 using our modifications to the standard IGC.

1. Introduction

Wide area deposition of homogeneously sized NanoParticles (NPs) is essential for various applications and devices that involve large surface area operation, like Solar cells, Photodetectors, etc [1–3]. Various vapor phase techniques are known for synthesis and deposition of NPs [4], including inert gas condensation (IGC). In IGC, NPs are generated from a solid source [5–12]. The atoms, ions and molecules generated from this solid source condense by collision with an inert gas to form NPs. A pressure difference between the condensation chamber and the deposition chamber of the IGC set-up is used to extract the NPs through a hole connecting the two chambers. The extraction through the hole results in the direct deposition of NPs on the substrate, placed in front of the hole, in the deposition chamber [5]. One of the major limitations of this standard IGC technique is the small (approximately 1 mm^2) area of deposition. By increasing the number of holes or by replacing hole(s) with a slit we demonstrate that a thin film of nanoparticles covering several 100 mm^2 can be deposited using IGC.

2. Experimental details

The IGC process for synthesis of NPs has been described in our previous work [5]. In the vacuum chambers of our standard IGC, the solid copper gasket sealing the flanges between the condensation chamber and the deposition chamber had a single 2 mm diameter hole in the center. Usually, only a small deposition area (approximately 1 mm^2) is covered with nanoparticles, as can be seen in Fig. 1. This limitation was overcome by introducing a simple modification (see Fig. 2) to the existing IGC system.

The 2 mm hole was replaced to increase the area of deposition. The single-hole solid copper gasket (Fig. 2a and b, and Fig. 3a) that connected the condensation chamber and the deposition chamber in standard IGC was replaced with a multi-hole solid copper gasket (Fig. 2c and Fig. 3b). This multiple-hole gasket was drilled with an array of 25 holes, 0.31 mm in diameter, at a separation of 3 mm from each other. This initial modification resulted in the deposition of homogeneously sized

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http://dx.doi.org/10.1016/j.vacuum.2015.01.019

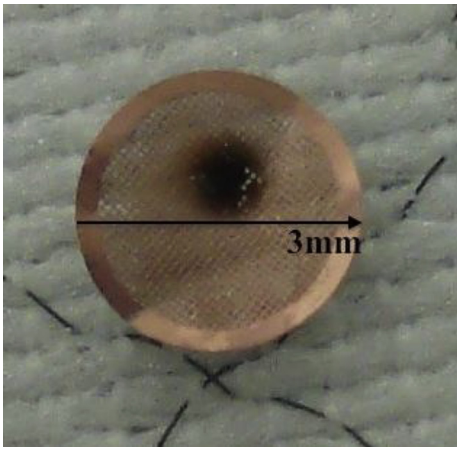

Fig. 1. TEM grid, 3 mm in diameter, with NPs deposited over an area of approximately 1 mm^2.

NPs over a 144 mm^2 substrate area. The deposition consisted of several spots of nanoparticles in the areas on the substrate that were in front of the holes.

In order to achieve deposition over the entire substrate area the set-up was further revised: The multiple hole gasket was replaced with solid copper gasket (Fig. 2d and Fig. 3c) in which a single slit was machined, and the substrate was continuously rotated during the deposition process. An 8 rpm motor was used for this rotation. This slit was 20 mm in length and 0.13 mm in width. The substrate was attached to a rod, which was rotated using a motor, which in-turn rotated the substrate.

The distance between hole(s)/slit and substrate was in the range of 0.7–1.5 cm. Fig. 3 shows the photograph of the actual solid copper gaskets used. The total area of the 25 holes and the single slit was nearly equal to the area of the single 2 mm hole. Thus no upgrade in the vacuum system was required in the modification. The same level of pressure difference was maintained using the same vacuum pump set-up as used for the standard IGC.

A further modification made the replacement and cleaning of the gaskets easier. For this modification a custom-made gasket (Fig. 4a and b) was designed in which the hole or slit patterns were drilled onto smaller replaceable copper disks. In this set-up, only the disk needed to be replaced in order to change the deposition pattern. The threaded retainer rings hold the disk on the reentrant-tube on the gasket, and make the replacement of the multiple hole or single slit disk easy. Fig. 5a and b show the replaceable multiple hole and single slit copper disks. The multiple hole disk pattern has 25 holes, 0.35 mm diameter and at a separation of 4 mm from each other, and the single slit disk pattern has a slit 14 mm long and 0.37 mm wide.

An important precaution for the custom-made gasket was that there should be no raised edges in the path of flow of NPs from sputtering target to the hole(s) or slit. The retainer rings were kept

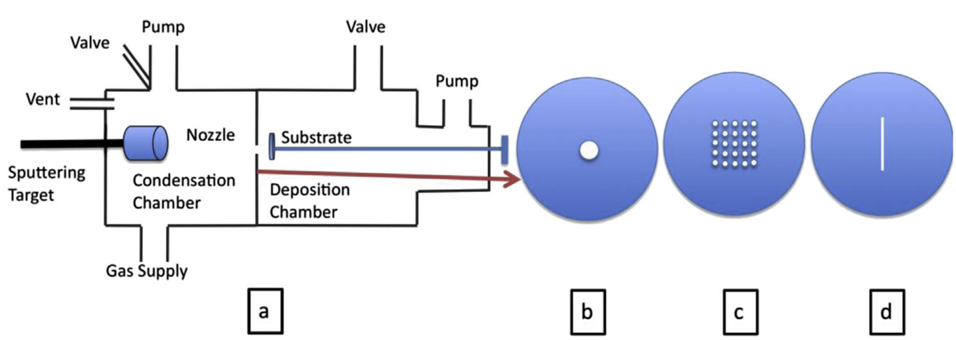

Fig. 2. (a) Schematic diagram of the standard IGC with a single hole gasket; (b) Schematic of the single hole gasket used in the standard IGC set-up; (c) Schematic of multiple hole gasket that replaces the single hole gasket in *a* for the modified IGC set-up; (d) Schematic of single slit gasket that replaces the single hole gasket in *a* for the modified IGC set-up.

(a) (b) (c)

Fig. 3. Photographs for actual solid copper gaskets used in our laboratory: (a) 12 cm diameter copper gasket with single hole 2 mm in diameter; (b) 12 cm diameter copper gasket with 25 holes, each 0.31 mm in diameter, 3 mm apart; (c) 12 cm diameter copper gasket with a single slit 20 mm long and 0.13 mm wide.