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Novel fabrication method for integration of template grown metallic nanocones with controllable tip diameter and apex angle

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Abstract: Conical metallic nanostructures, due to their geometrical and physical properties, are advantageous compared to cylindrical nanowires in applications like electron field emission cathodes. In this paper a new method for fabrication and integration of vertically aligned metallic nanocones with random distribution is reported. The nanocones are deposited electrochemically at temperatures about 60 °C and lower. An area of ca. 1 cm^2 is covered with nanocones. The density of nanocones ranges between 6×10^4 to 2×10^6 cm^{-2}, which gives a pitch range of 23 to 7 µm. With this process the growth and integration of nanocones made of different materials like e.g. Au, Ni and Cu are enabled. The tip diameter of the cones can be modified between 50 to 700 nm and the base diameter between 2.5 to 7 µm, i.e. apex angles between 5.9° and 16.6° can be obtained. The surface roughness of the nanocone arrays is ±0.2 µm.

Keywords:nanocones, track-etched membranes, electroplating, electron field emission, nanocones

1. Introduction

Metallic nanowires possess an enormous application potential in a wide range of research and development. Due to their unique physical properties they can be applied in different sensing elements, such as optical, biological, chemical and inertial sensors. In addition, they have also attracted significant attention due to their field emission properties in terms of their applicability in microelectronic vacuum devices [1]. The biggest obstacle for realizing these novel devices and sensors is the technological shortage in oriented and organized integration of vertical nanowires in 3D microsystems.

Changing the shape of cylindrical wires to conical geometry gives them a larger base, thus a better thermomechanical stability. For example, Spindt-type field emitter arrays (FEAs) are well known conical shaped electron field emitters [2]. Such arrays guarantee large field emission currents up to 150 µA per cone but have disadvantages like complicated fabrication procedure and high manufacturing costs [3]. Among Spindt-type cathodes and CNT-cathodes [4],[5] arrays of metallic nanowires or cones can be considered as a promising cost-efficient alternative for traditional thermionic electron sources.

In this paper we report on a novel method for *in situ* fabrication and integration of metallic nanocones with modifiable geometry. This is developed from a methodology for *in situ* integration of metallic cylindrical nanowires in 3D microsystems at room temperature up to 60 °C [6]. This fabrication temperature is drastically below fabrication temperatures of CNTs. With this method we enable also flexible variation in different parameters like electrode geometry and also thickness, density, height and even material of the nanocones and -wires. This shall serve as a fundament for further investigations and improvements of the field emission properties of metallic nanocones in cryogenic ambient.

2. Asymmetric etching of ion-tracked polymer templates

Using a polymer template instead of Aluminium oxide membranes became a well-established technique over the recent years [7]–[10]. The irradiation of polymer foils with swift heavy ions of MeV-GeV kinetic energy damages the polymer chain along the particle track [11], [12]. Consequently, etching the polymer foil one can observe that the etch rate along the particle tracks (V_t) is much higher than the bulk etching velocity (V_b), see Figure 1. Thus etching the particle tracks in the polymer foil can be used to create a porous foil to grow cylindrical or conical metallic nanostructures within [7], [13]–[15]. V_t is not constant and correlates with the energy-loss function of particle along the track. Subsequently, the etch rate at the two sides of the foil are different. To reach conical shaped pores the etch process must be performed asymmetrically at the ion entry side [16] while a symmetrical etching leads to cylindrical pores. In addition, the lateral etch rate (V_l) changes