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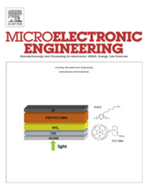

Diamond nanoprobes for electrical probing of nanoelectronics device structures

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ABSTRACT

Electrical nanoprobing inside scanning electron microscopy (SEM) systems has become a routinely used characterization technique for electrically measuring prototypes of the most advanced nanoelectronics device structures. Tungsten wire needles with a sharpness of about 50–100 nm are commonly used as probe tips in these measurements. They suffer unfortunately from tip oxidation effects and need to be initialized. Moreover, they are too soft to directly probe on semiconductor materials such as Si and Ge. Therefore, harder probe tips are required which can withstand high pressures (in GPa range) and oxidation. In order to meet these requirements, we have developed doped diamond tips and integrated them into metal cantilevers. They have an in-plane geometry which allows direct visibility in the SEM system of both the area to be contacted and the tip apex. Furthermore, the probes are mounted at the end of a metal wire which ensures compatibility with existing nanoprobing systems and allows for convenient probe handling. This paper describes the probe concept and discusses the probe fabrication process in detail. Manufactured probes are presented and their suitability for measurements on a Ge calibration structure is demonstrated. Our work shows that the developed diamond nanoprobes overcome the disadvantages of existing tungsten wire probes and enable the probing of semiconductor materials.

1. Introduction

Electrical nanoprobing combines scanning electron microscopy (SEM), nanomanipulation and electrical measurements in one tool and has become a routine analysis tool for measuring prototypes of the most advanced nanoelectronics device structures and materials [1,2]. A small but crucial component of this method is the probe tip. Manually etched W-wire tips are mostly used today for contacting the region of interest on the sample [3]. Unfortunately, such W tips are prone to oxidation and therefore need to be initialized before the measurements to remove the surface oxide by local heating of the apex region. Moreover, they have a limited spatial resolution of typically about 50–100 nm and are too soft for electrical measurements on semiconductor materials such as Si and Ge. Therefore, micro-fabricated probes for nanoprobing are highly desired which do not oxidize, allow for higher spatial resolution and can also be used for probing semiconductor materials. Diamond tips as used in scanning spreading resistance microscopy (SSRM) [4,5] have been demonstrated for nanoprobing [6] but such probes must be fully compatible with the existing nanomanipulators (without the need of special probe adapters like clamping holders typically used for SSRM).

Therefore, we have developed micro-fabricated probes consisting of conducting diamond tips integrated into metal cantilevers which are connected to manipulator-compatible metal rods. They overcome the disadvantages of W-wire probes: no tip oxidation, higher hardness/lower wear, and improved spatial resolution. Our probes allow for direct probing of semiconductors which is not possible with W-tips. This work presents the probe concept, explains the fabrication process using state-of-the-art 200-mm Si wafer technology and shows manufactured probe devices. Their use for nanoprobing measurements is demonstrated.

2. Probe fabrication and design

Fig. 1 shows the sequence of fabrication steps schematically. The substrate is a 200 mm diameter (100)-Si wafer. First, an 800 nm thick boron doped nanocrystalline diamond (NCD) layer

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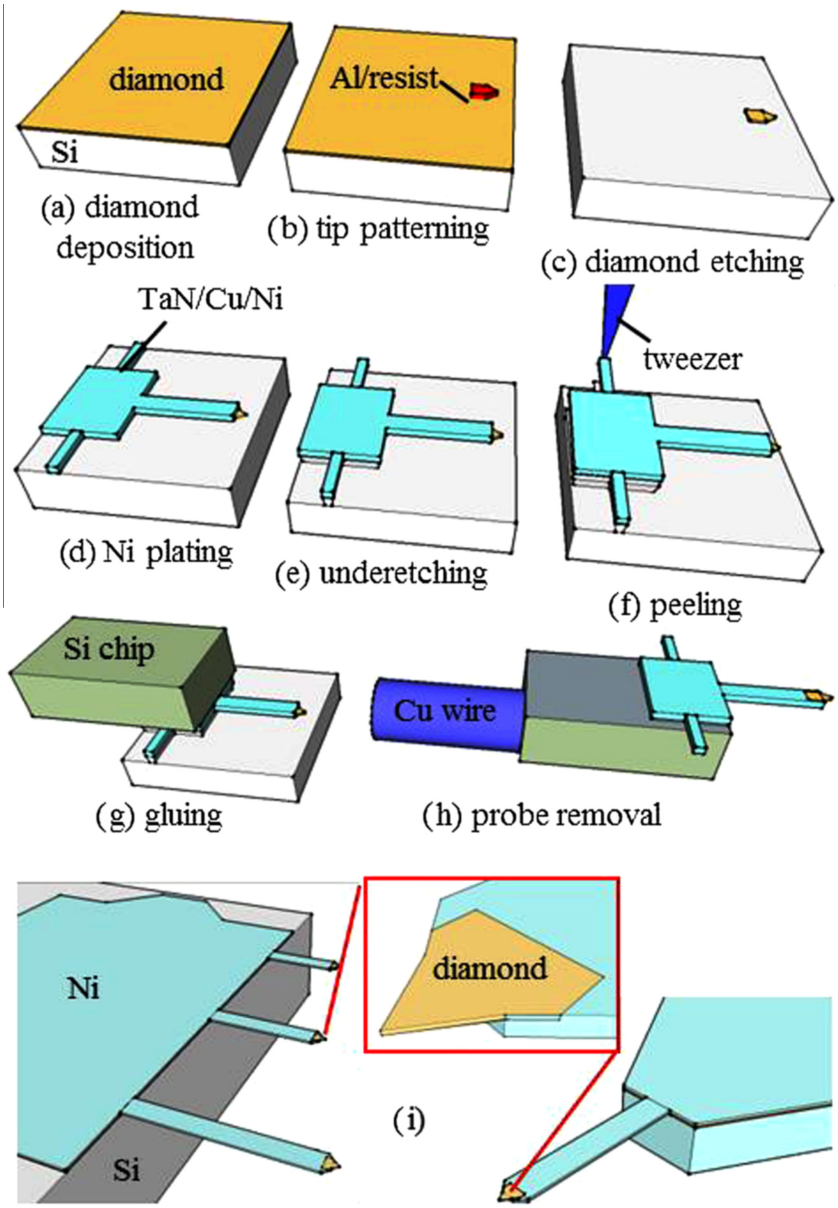

Fig. 1. Schematic view of probe process and configuration.

is deposited using a hot-filament chemical vapor deposition (HFCVD) system (model 655 by sp3 Diamond Technologies) in a flowing gas mixture comprised of CH_4 and H_2 at a pressure of about 6 Torr and a substrate temperature of about 850 °C (Fig. 1a). The boron doping is achieved by adding trimethylboron (TMB) into the gas phase which gives a boron concentration of about 2.5% inside the NCD layer [7]. A 500 nm thick Al film is then sputtered onto the diamond film and the diamond tip area is patterned by the first lithography step. The Al film is structured by wet etching (Fig. 1b) and the diamond is etched by reactive ion etching (RIE) in an O_2:SF_6 plasma. The remaining Al film is then removed by another wet etching step (Fig. 1c). A metal stack of 30 nm TaN + 50 nm Cu is sputter deposited onto the substrate whereby the TaN acts as adhesion and peel-off layer and the Cu as electroplating seed layer. The cantilever and probe membrane area are patterned by the second lithography step. A 4–6 μm thick Ni film is then deposited using electroplating and the photoresist is removed afterwards (Fig. 1d). Next, the electroplated Ni film is used as an etch mask for the removal of the still exposed Cu layer by wet etching and the underlying TaN layer by RIE.

The diamond tips and Ni cantilevers are then underetched in KOH (Fig. 1e). The probes can now be removed from the wafer using a pair of tweezers. This is done by a peel-off step whereby the holder membrane is gradually peeled away from the substrate whereby overcoming the adhesion of the TaN to Si interface (Fig. 1f). This peel-off approach is described in detail elsewhere [8]. Metallized holder chips are then glued against the holder membranes using a conductive glue (Fig. 1g). The probes are then removed from the wafer and are finally fixed onto the flattened end of a 3 cm tinned Cu wire using a conductive glue (Fig. 1h).

Fig. 1i illustrates schematically the two actual probe configurations: one probe type uses three cantilevers with a length of 440, 210, and 150 μm allowing for selecting an appropriate spring constant, and hence force range, within a range of about 1–90 N/m for the electrical measurement. The cantilever width is 50 μm. A specific cantilever is chosen by bending the other ones away using a