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# Building and testing submicrometer metallic (gold) air-bridges for nanotransport applications

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**Abstract**

The properties of submicrometer gold air-bridges are investigated for their suitability as elements of an electronic device. The fabrication procedure of a gated vertical quantum dot resonant tunneling diode structure implementing air-bridges is presented as a demonstration. Our investigations show that air-bridges produced by multiple acceleration voltage lithography exhibit excellent mechanical and electrical stability for nanotransport application.


*Keywords:* Electron beam lithography; Nanostructures; Air-bridges

## 1. Introduction

In light of continued miniaturization of semiconductor devices and the implementation of new materials in devices, connection and isolation of functional areas is becoming an important issue. The standard way of connecting small elements located close to each other by covering them with an insulator, drilling openings in appropriate places, and filling them with metal for wiring on top of the insulator, can be difficult, or even impossible. In such cases, implementation of conductive air-bridges is a solution. This work is an investigation of submicrometer metallic air-bridges intended to serve as functional elements in nanotransport devices. Expanding on a multilayer resist technique previously used to fabricate submicrometer air-bridges in nanoscale transport structures [1–3], we have developed a fabrication method for submicrometer air-bridges which differs from the method used by others and which we introduced in [4]. The approach is based on multiple accelerated voltage electron beam lithography (EBL). Fig. 1 presents a gallery of complex three-dimensional structures fabricated using this technique. The

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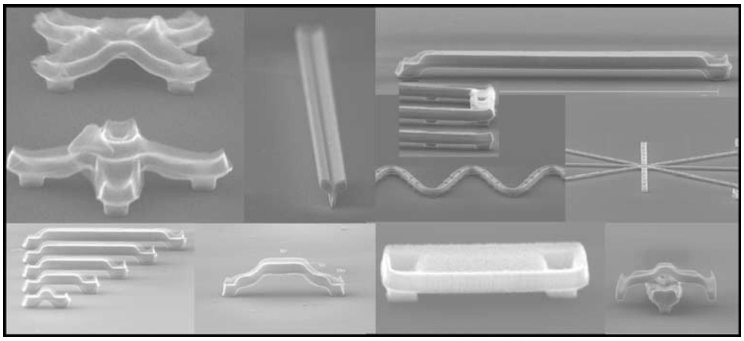

Fig. 1. A gallery of metallic air-bridges fabricated by multiple acceleration voltage electron beam lithography.

method takes advantage of the dependence of the penetration depth of electrons into polymer resists on the acceleration energy of the electrons, which continuously varies from ∼100 nm at 1 kV to several microns at 30 kV. This voltage range is routinely used in scanning electron microscopes for direct e-beam writing.

Though the method presented here can be used with many polymer resists, we have chosen polymethylmethacrylate (PMMA) for its simple formulation with no extra sensitivity enhancers or other additives. It can therefore be relied upon to provide reproducible electron paths, as well as sensitivity and contrast parameters. The molecular weight does not affect the electron penetration depth. Furthermore, the cross-linking property of PMMA at high exposure doses is a useful feature, allowing the fabrication of supporting non-conductive posts useful for the fabrication of long air-bridges.

In our method, we vary the acceleration voltage in the lithography process to write a three-dimensional profile in a 0.8–3 μm thick resist film. After development, metal evaporation, and lift-off, metallic air-bridges are obtained. For air-bridges to be useful in nanostructure applications, they must be mechanically stable and provide good electrical contact between elements of the device. How this can be achieved using the present technique is the main topic of this paper. As an example of a specific application, we will discuss in detail the fabrication of a gated vertical quantum dot resonant tunneling diode.

## 2. Details of the fabrication procedure

For a full description of the air-bridge fabrication procedure, we direct the reader to our recent paper [4]. In the present work, we will focus on details of the technique which are especially important for the practical implementation of bridges into full device structures.

A precise knowledge of the behavior of PMMA at different acceleration voltage and electron irradiation dose is the key to successful air-bridge fabrication. In [4], we presented the dependence of the effective electron penetration depth into PMMA on the energy for a range of voltages from 3 to 13 kV which can be used in the writing of bridge spans. Here, in Fig. 2(a), we present a more detailed reference table of penetration depths for the range of voltages and doses, which we found most appropriate for the production of air-bridges in transport nanostructures. The data in the table were obtained for a 1.35 μm thick PMMA film with an average molecular weight of 950,000 (950k), on an undoped GaAs substrate. The thickness was determined for patterned PMMA single lines. In actual structures, we use 1–1.5 μm thick PMMA 950K resist for air-bridge fabrication and, as a rule, bridges are well separated from each other. The development is perfomed by emerging the sample for 4 min in a mixture of methyl isobuthyl ketone (MIBK) and isopropanol (IPA) in a ratio of 1:5.

High acceleration voltage is used to expose the locations of air-bridge posts. We use it also to