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# Large insulating nitride islands on $Cu_3Au$ as a template for atomic spin structures

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ABSTRACT

We present controlled growth of c(2 × 2)N islands on the (100) surface of $Cu_3Au$, which can be used as an insulating surface template for manipulation of magnetic adatoms. Compared to the commonly used Cu(100)/c (2 × 2)N surface, where island sizes do not exceed several nanometers due to strain limitation, the current system provides better lattice matching between metal and adsorption layer, allowing larger unstrained islands to be formed. We show that we can achieve island sizes ranging from tens to hundreds of nanometers, increasing the potential building area by a factor $10^3$. Initial manipulation attempts show no observable difference in adatom behaviour, either in manipulation or spectroscopy.

## 1. Introduction

The ability to position individual magnetic adatoms into a specific arrangement on a surface holds great potential for atomic scale studies of quantum magnetism [1]. A particularly successful template for the placement of transition metal atoms is the c(2 × 2) reconstruction of nitrogen on the Cu(100) crystal surface [2], which provides a self-terminated insulating monolayer, separating the atomic spins from the conduction electrons in the metal below [3]. Due to its covalent structure, the copper-nitride surface provides significant magneto-crystalline anisotropy [4] and allows for tunable spin-spin coupling between neighbouring atoms, both ferromagnetic and anti-ferromagnetic [5,6]. The combination of these techniques has given rise to a range of seminal experiments, including the construction of a 96-atom magnetic byte [7], the observation of spin waves in a one-dimensional spin chain [8], and the atomically precise study of various highly entangled spin systems [9,10].

As atom manipulation techniques become more reliable [11], the size of atomic structures is only limited by the maximum available continuous building area. In the case of copper-nitride, this limit is imposed by the nitrogen islands. Due to a 3% lattice mismatch between the adsorption layer and the underlying Cu(100) crystal, island sizes are strain-limited to ~ 5 nm × 5 nm — or, on saturated surfaces up to 20 nm × 20 nm [12] — hampering the assembly of any spin structure larger than that. Here, we present growth of nitride islands on a different metal substrate: the $Cu_3Au(100)$ surface. With a lattice constant $a = 0.375$ nm [13], its lattice much better matches the one of copper-nitride ($a = 0.372$ nm [14]) than the Cu(100) surface ($a = 0.359$ nm [15]) does. By properly tuning growth conditions, we can routinely grow islands ranging from tens to hundreds of nanometres across, vastly increasing the area on which spin structures can be assembled.

## 2. Experimental details

The experiments were performed in a scanning tunnelling microscope (STM) operating in ultra-high vacuum (UHV) and cryogenic conditions. During measurements the pressure was $< 5 \times 10^{-10}$ mbar and the temperature was between 1.4 K and 1.5 K. Sample preparation was performed *in situ* in a UHV chamber connected to the STM, which has a base pressure of $< 4 \times 10^{-10}$ mbar. The preparation chamber is equipped with standard sputtering and e-beam annealing equipment, and has inlets for pure argon and nitrogen (99.999%).

We monitor the sample temperature during annealing by means of a pyrometer. Due to stray radiation originating from the filament behind the sample, the actual temperature readout, while reliable, is overestimated. In order to approximate the real temperature of the sample during annealing, we record the cooling curves after turning off the filament, and extrapolate back.

We used a commercial $Cu_3Au$ crystal grown by *Surface Preparation Laboratory*, which was cut along the (100) plane with ~ 0.1° accuracy and polished to a roughness <0.03 μm. Prior to growing the nitride islands, the crystal was cleaned with multiple rounds of argon sputtering at 1 kV followed by annealing. This process was repeated until a clean surface with large plateaus was observed in STM images.

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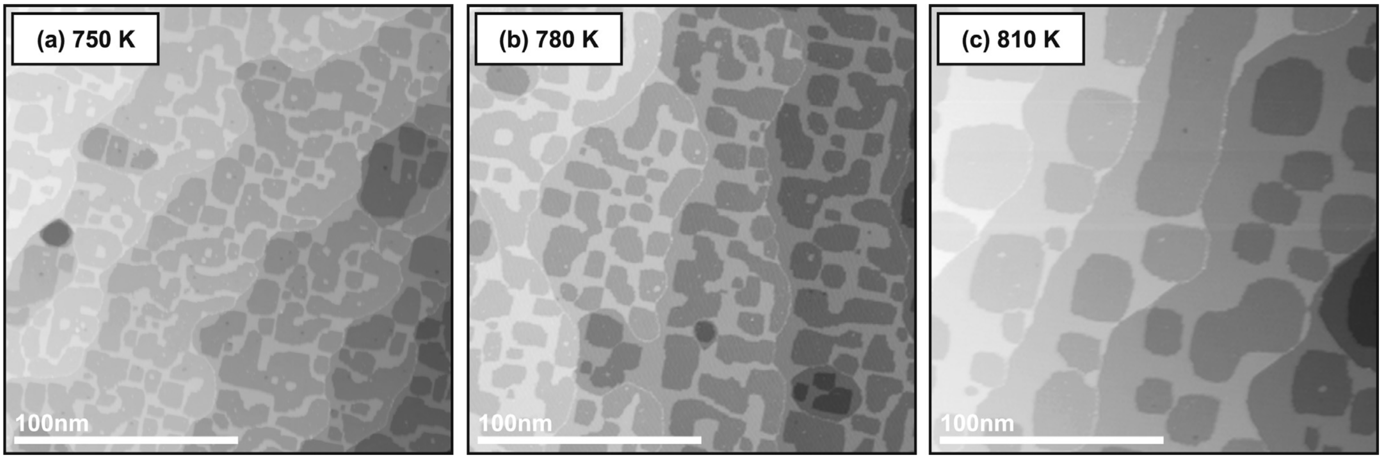


**Fig. 1.** STM images of nitrogen islands on ordered $Cu_3Au(100)$ after 5 min of annealing at (a) 750 K (b) 780 K and (c) 810 K. The images were acquire at a temperature of 1.5 K with constant current at (a) 0.1 nA and 0.2 V, (b) 0,1 nA and 1 V and (c) 0.4 nA and 0.2 V. The nitrogen islands appear as darker areas surrounded by brighter areas, which are bare $Cu_3Au(100)$.

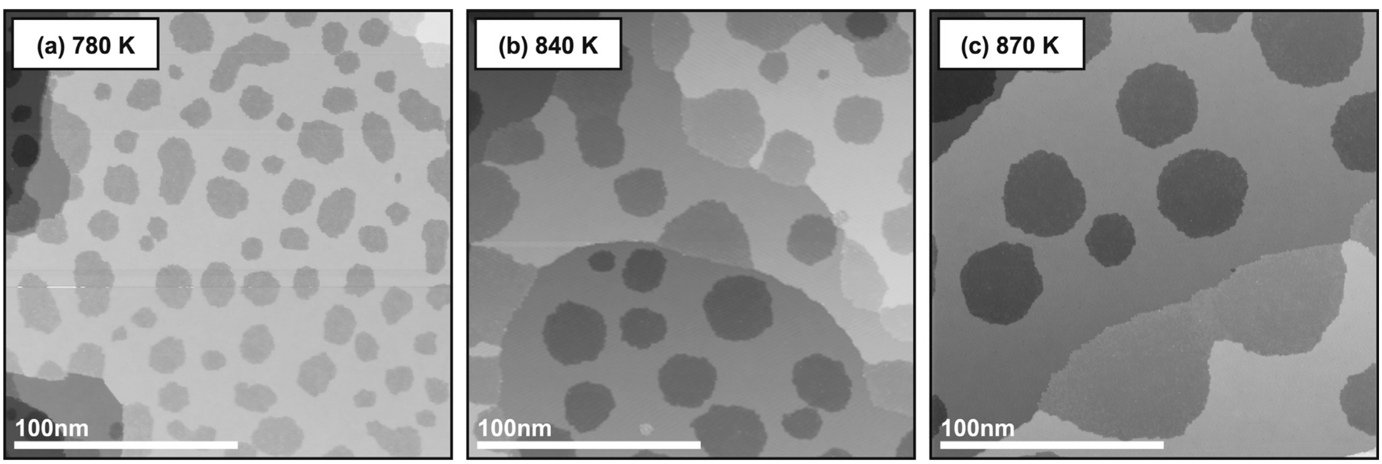


**Fig. 2.** STM images of nitrogen islands on disordered $Cu_3Au(100)$ after 5 min of annealing at (a) 780 K (b) 840 K and (c) 870 K. The images were acquired at a temperature of 1.5 K with constant current at (a) 0.1 nA and 50 mV, (b) 0.2 nA and 100 mV and (c) 0.2 nA and 50 mV.

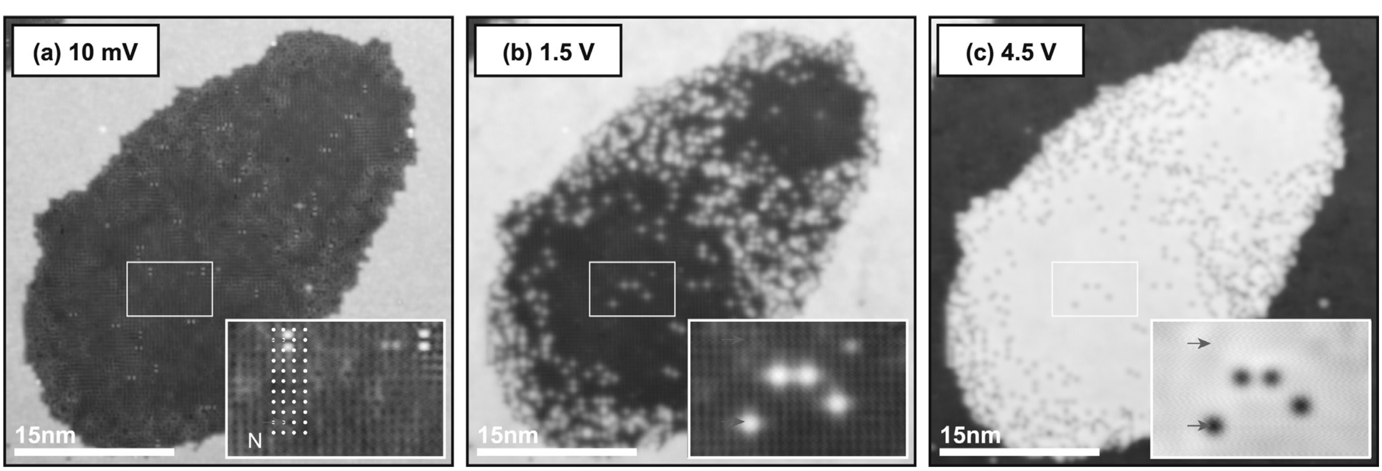


**Fig. 3.** STM images of a nitrogen island on disordered $Cu_3Au(100)$, scanned at a constant current of 0.5 nA and a bias of (a) 10 mV, (b) 1.5 V and (c) 4.5 V. The surface was annealed 5 min at 840 K after nitrogen sputtering. The insets are higher resolution scans of a section of the nitrogen island taken at identical measurement parameters. The corresponding area on the island is indicated by a white rectangle. For (a) and (b) the nitrogen islands are darker than the surrounding bare $Cu_3Au(100)$. This contrast is inverted for (c). In the inset of (a), the dots correspond to the nitrogen position in the CuN layer. To avoid clutter, copper positions, which are located in between nitrogen nearest neighbours, are omitted. The arrows, repeated in all three insets, indicate the two types of defect described in the text.. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)