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Development of process for far infrared sensor fabrication

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Abstract

The production of bolometers involves various processes. Those which are most likely to interfere with the operation of the sensors are the depositon of the porous gold (gold-black) layer used as an infrared absorber and the poly-Si etching used to form resistive devices. In this paper, we present an appropriate process for the deposition of porous gold for far-infrared detection, and provide a comparison of wet and plasma etching of poly-Si.

Keywords: Bolometer; Gold-black; Poly-Si; Etching; Microfabrication

1. Introduction

Thermal infrared detectors, such as bolometers, measure the intensity of radiation via the increase in temperature of an active element. For the transformation of infrared radiation into heat, the active element is covered with an absorbing layer, but this layer must have high absorbance and small mass or small heat capacity, so that the responsitivity of the sensor will not decrease, i.e. so that the time constant will not increase [1,2]. An efficient infrared absorbent layer must therefore combine high absorption with low film mass. The most effective mechanism for the promotion of infrared absorption is high porosity, since this corresponds to low heat capacity. Gold-black films offer a possible option, since they are extremely porous and have a low thermal mass. However, highly porous films are difficult to handle, since they are extremely vulnerable and can easily be destroyed, even by a simple touch. One solution to the problem, is the deposition of the porous films as the final step in the technological process, but this is not always feasible and on-going research attempts to develop new possibilities, compatible with the microelectronics process.

The use of micromachining techniques to manufacture the thermal infrared (IR) detectors greatly increased the directivity of these devices, such as pyroelectrics and bolometers. These techniques enable an increase in the thermal insulation of the devices [3]. Bolometers are formed by a temperature dependent resistor and an IR absorber [4]. The resistor should have a large temperature coefficient of resistance (TCR) [5].

For the manufacture of bolometers, a thermally and electrically insulating membrane is fabricated, and a temperature-sensitive element is deposited onto this membrane. Sensitive elements which can be deposited at low temperatures include vanadium oxide [6], metals [7,8] and amorphous semiconductors [9]. Although good results have been obtained with all of these materials, none of them can be considered an optimal one. The resistance of metals varies as a function of temperature; moreover, vanadium oxide is not a standard material in integrated circuit (IC) technology, and amorphous semiconductors are subject to a large amount of low frequency ($1/f$) noise.

The most obvious candidate for the active material is poly-Si [10]. Its TCR and electrical conductivity can be easily controlled by doping and it is obviously fully compatible with IC technology [11,12]. A large TCR leads to a significant change in bolometer resistance with only a small temperature increase (Eq. (1)).

$$\mathrm{TCR} = \frac{1}{R} \cdot \frac{\mathrm{d}R}{\mathrm{d}T} \tag{1}$$

The structure of a bolometer is shown in Fig. 1. Thermal insulation is defined by the thermal conductivity and the geometry of the arms support.

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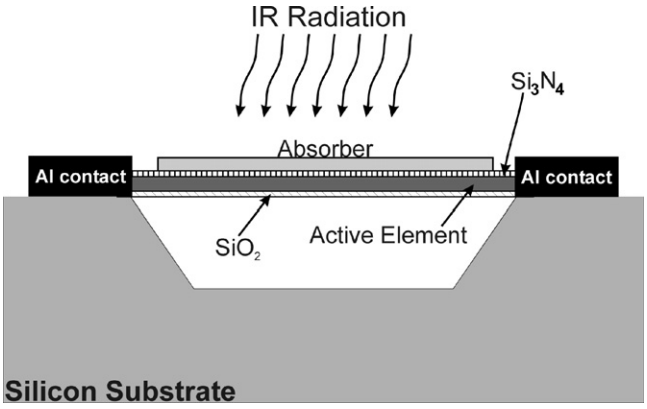

Fig. 1. Structure of microbolometer.

The primary objective of this research was the development of a deposition process capable of obtaining gold-black layers with a high coefficient of absorption that would be good absorbers of the IR radiation in the submillimeter/far infrared spectrum range, when deposited onto electronic materials [13], such as silicon, silicon oxide and silicon nitride; moreover, the optimization of the poly Si etching process in the formation of resistors was investigated.

In Section 2 we describe the process used to produce the bolometer, and in Section 3 the results obtained in development of the process. We present the conclusions in Section 4.

2. Experimental

The most common procedure for the fabrication of the porous layers, is the evaporation of gold in an atmosphere of nitrogen. Here we used thermal evaporation of gold with a purity of 99.999%, to obtain a porous gold (gold-black) layer. Gold wire (10 cm) is evaporated from an electrically heated tungsten basket. The black-gold depositions were performed at a pressure of 2.66×10^{-4}, 4.00×10^{-4}, 5.32×10^{-4}, 7.98×10^{-4} and 10.64×10^{-4} mbar, on various substrates (silicon, silicon oxide and silicon nitride), located at a distance of 5 cm from the gold source, in a nitrogen atmosphere. The electrical conductivity of the gold-black layer depends on the parameters of evaporation. Fig. 2 provides a schematic drawing of the evaporation chamber used for gold-black deposition. This conductivity can be reduced by controlling the foreign gas present in the evaporation atmosphere; here this gas was nitrogen.

The vacuum chamber was first evacuated to a base pressure better than 1.33×10^{-6} mbar, for several hours, followed by the premelt of the gold wire, in order to allow some gold evaporation from the tungsten basket and the consequent cleaning of the surface of the gold source. Then, nitrogen gas, controlled by a mass flow meter, is continuously leaked into the vacuum chamber until the desired pressure is reached. This procedure takes about 20 min and helps to reduce the content of residual gases, especially oxygen, which is known to lower the absorbance of gold-black layers. In the final evaporation step, the processes are followed by the turning off of the electrical current to the tungsten basket, although the flow of nitrogen into the evaporation chamber is kept constant for 15 min more to clean the reactor.

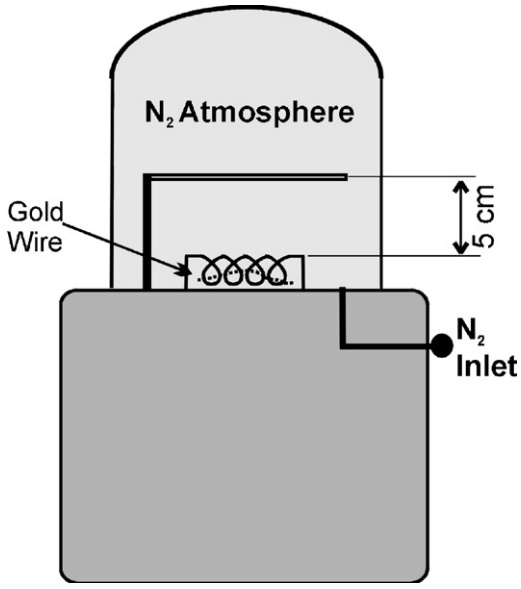

Fig. 2. Schematic drawing of evaporation chamber used in gold-black preparation.

The production of a silicon bolometer, as illustrated in Fig. 3, involves various steps, including the following: (A) the deposition of silicon oxide, (B) deposition of poly-Si, (C) deposition of silicon nitride, (D) deposition of aluminum pads, (E) deposition of gold-black layer and (F) etching of silicon oxide with buffered HF solution.

In the poly-Si deposition step, a SiH_4 gas diluted in H_2O is used to deposit a 0.5 μm, 1.0 μm or 2.0 μm thick poly-Si layer on top of a silicon oxide layer, by a reduced pressure chemical vapor deposition (CVD) method at a temperature of 800 °C. This layer is implanted with a low dose of boron of 3×10^{13} B cm^{-2} at an energy level of 40 keV, to obtain the desired resistivity and TCR. This layer is then etched to produce the resistor structure. In this research, two different etching processes were tested: wet etching using HNO_3:H_2O:HF solution and reactive ion or plasma etching with SF_6:CF_4:CHF_3 chemistry. In both cases, a standard photolithographic process was used. For the wet etching, photoresist 1350 was used. After established with pre-testing the rate of etching of poly-Si, the wafers were etched for 7 min at room temperature. After etching, the samples were rinsed in deionized water and isopropylic alcohol (IPA), and then dried in an oven at 80 °C for 30 min. For the plasma etching process, photoresist 5214 was used, with the samples etched using a power of 5 W, pressure of 0.1064 mbar, and a polarization bias of 180 V. The etching rate obtained was approximately 16.67 nm/min.

3. Results and discussion

Figs. 4 and 5 show two XSEM micrographs of the gold-black samples prepared at deposition pressure of 7.98×10^{-4} mbar. The first provides a top view of the gold-black film with a magnification of 25,000×, and the second a side view of the same sample with a magnification of 22,000×; both taken using an energy