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Fractal properties of gold, palladium and gold–palladium thin films on InP

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A B S T R A C T

Thermal interaction of indium phosphide (InP) bulk compound semiconductor with thin gold metal films was investigated in the course of the present work. The interaction of the InP/Au system resulted in a pattern showing fractal dimensions. The temperature dependence of the fractal parameters was investigated in a broad temperature range from 200 to 600 °C. No significant temperature dependence of the fractal dimension was observed.

The same calculations will be presented for Au/InP and AuPd/InP systems. Our calculations show that the Pd-based contacts have a different behaviour than AuGe metallization where a strong temperature dependence of the fractal number was observed earlier.

Another topology measure, the structural entropy is also calculated for the samples. The structural entropy is usually applied for determining the type of the localization of charge distributions, but it can also be used for generalized charges, such as the lightness of the pixels of an electron microscopy picture.

1. Introduction

Indium phosphide (InP) is a key material for both optoelectronics and microwave devices. Ohmic and Schottky contacts are substantial parts of these compound semiconductor devices. High power density, high operational speed and reliability are the most important factors determining the materials science issues of the components used in these thin metal based layers.

Palladium appears to be an important component in contact metallization [1,2]. For contacting *p*-InP palladium can be co-deposited with gold and zinc [3]. After an appropriate heat treatment this metallization results in an Ohmic contact. For forming Schottky contacts titanium metallization can be applied [4].

For the *n*-InP Ohmic contact AuGe, AuPtTi and AuPtTiNiAuGe multilayers can be used [5]. For forming Schottky barriers on *n*-InP palladium [6] and gold [7] can be applied. If gold is combined with a single monolayer of Sb a large barrier height can be obtained [7].

In the device technology the deposition of multilayer metallization is followed by a heat treatment, usually under non-equilibrium conditions. During this process, an interaction between the compound semiconductor and the metallization results in out-evaporation of the volatile component; in the case of a ternary compound As, P and Sb will diffuse out [8].

During the deposition and the subsequent annealing, palladium reacts with the InP and a separate phase formation of Pd_2InP [1] or Pd_5InP [9] takes place. The surface of the heat-treated metallization often shows a fractal character [10,11].

The aim of this study was a detailed investigation of the fractal behaviour of the Au, Pd and AuPd metallization on the bulk InP crystals after the heat treatment. These patterns are the results of the interaction of thin (50–85 nm) layers with bulk compound semiconductor materials.

2. Experimental

The gold, palladium and gold–palladium layers were deposited on *n*-(100) InP substrates. The wafers were cleaned and degreased in a 1:1 solution of HCl and H_2O_2, and, immediately before the metallization, etched in a 1% Br in methanol solution.

The heat treatment was carried out in the working chamber of a scanning electron microscope (SEM) [12]. A linear heat treatment rate of 150 °C/min was applied. During the heating an in-situ observation of the out-evaporation of the volatile component was observed and SEM pictures were taken at different temperatures. Some examples of the studied images are shown in Fig. 1.

The calculation of the fractal dimension was carried out by a box counting algorithm of the FracLac program of the Image package. Box counting is a method for determining the fractal

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✠ Prof. Imre Mojzes, prominent member of the nanoscience community in Hungary, passed away on 18 April, 2009.

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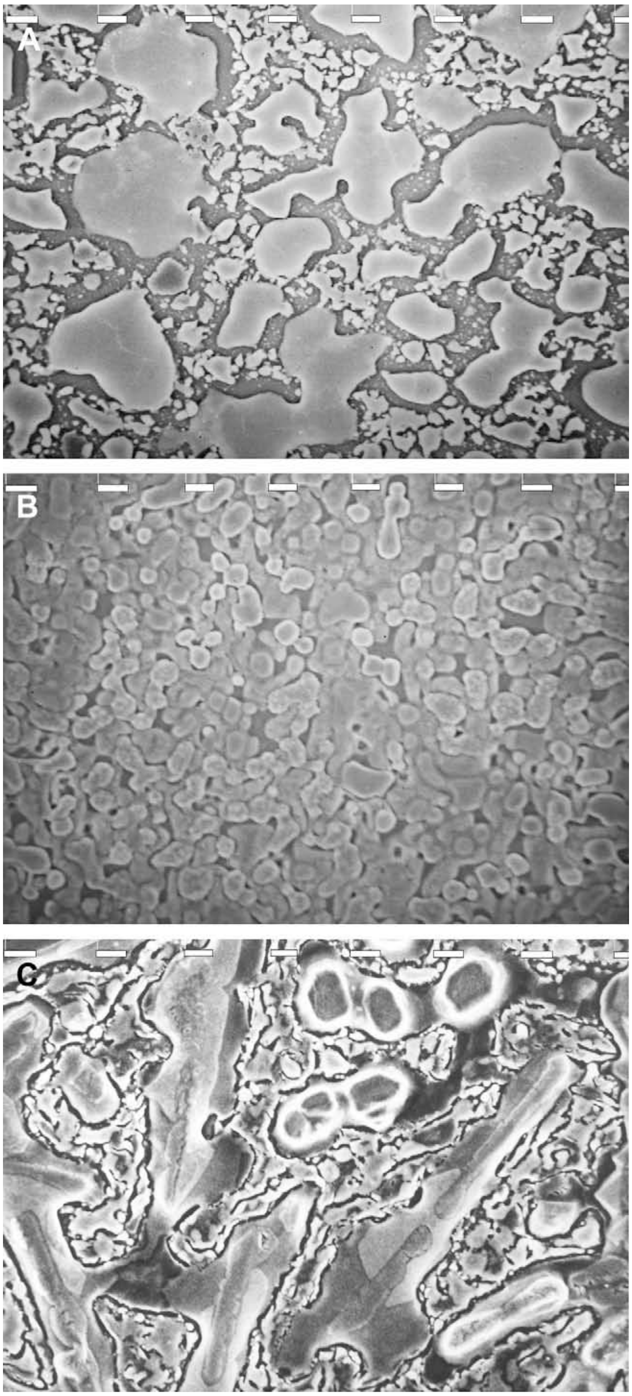

Fig. 1. Typical SEM picture of (A) the Au (60 nm)/InP(111) system at thermal treating temperature 525 °C, (B) the Pd (50 nm)/In P(100) system at $T = 510$ °C, and (C) the Au(85 nm) Pd (50 nm)/In P(100) system at 540 °C with 10 μm scale.

dimension according to its original definition by Hausdorff [13] and Mandelbrot [14]. Adopting the Hausdorff measure to black and white images results in the following steps. Let us count, how many boxes of diameter n are necessary for covering the white pixels. Next, cut the diameter of the box to $n/2$ (thus take the quarter of the area of it), and count the needed boxes again. Repeat these steps a few times (not after reaching the one pixel diameter) and plot the logarithm of the number of the boxes versus the number of steps (more precisely, the logarithm of the inverse-diameter of the boxes). The fractal dimension is the

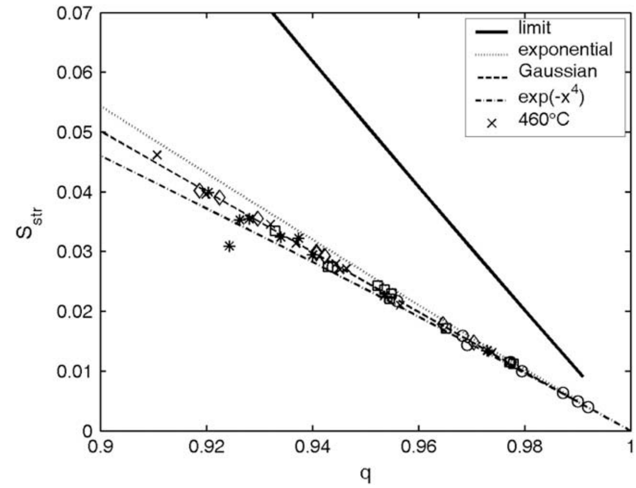

Fig. 2. Structural entropy versus the filling factor of the 460 °C Au (60 nm)/In P system. Five images were studied, each divided to 9 sub-pictures in order to generate more samples. The different signs mean different magnifications. Gaussian localization can be observed.

gradient of the straight line fitting to the resulting points. This definition is generalized for grayscale images, with various box shapes, but we remain with the original, black and white version, thus all the images have to be converted to black and white, by setting a threshold level.

The filling factor and the structural entropy [15] form another measure for characterizing the topology of the images, however, the structural entropy is zero for black and white pictures. These two quantities can give information about the shape of the two dimensional distribution, the grayscale image. The structural entropy S_{str} versus filling factor q plots of the given types of square integrable functions (like a Gaussian, an exponential peak) form a well defined line for each type of function. Comparing the $S_{str}(q)$ point of the studied picture with these known curves, the localization type of the forms in the picture can be determined.

The application of the filling factor and the structural entropy has a solid state physics basis. They were used for characterizing the localization of electron density distributions on a regular grid [15–20]. They are defined for grid distributions, like the pixel intensity $\{I_i, i = 1,\ldots,N\}$ of an SEM image, normalized according to

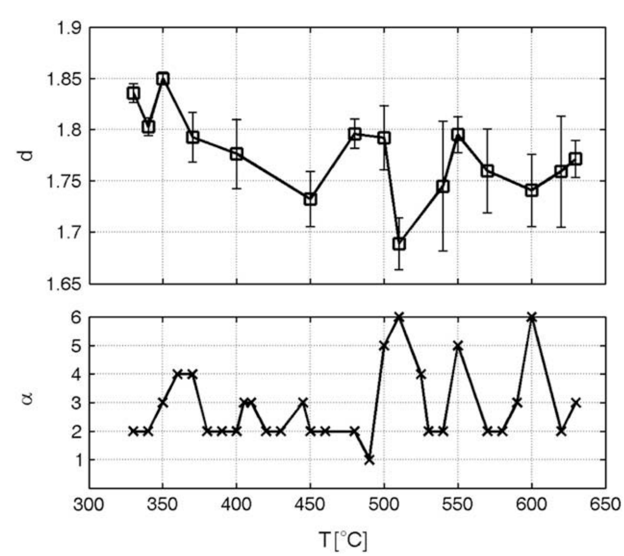

Fig. 3. The fractal dimension d and localization factor α of the 60 nm Au film on (111)-InP surface as a function of the heat-treating temperature T.