**Project leader: D. Davazogou**

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Master students: V. Assimakopoulos, D. Economou

Undergraduate students: S. Tsevas, C. Favre

**Projects Running:**

- PROTEAS PV System (EU)

**Objectives:**

The objectives of this group include research and development in the following:

a) Process and material development

b) Characterization of CVD films

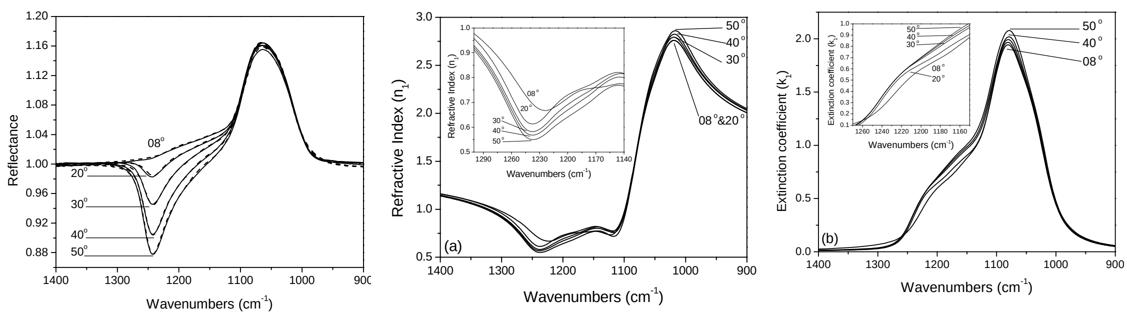
c) Applications

## Main results in 2004

### a) Characterization of CVD films

*V. Vamvakas*

The distribution of the Si-O-Si angles in $SiO_2$ films is obtained using FTIR transmission and reflection measurements at vertical and oblique incidence.
Of the main achievements of this year was the development of a theoretical model in order to describe FTIR transmission and reflection under oblique incidence. Using this model the refractive index of $SiO_2$ films was extraxted at various angles. Results for films deposited from $SiH_4$+$O_2$ are shown in *fig. I.4.1.*




*(a)* *(b)* *(c)*

***Fig. I.4.1:*** *(**a**, left) Measured reflection spectra (broken lines) and simulated ones (continuous lines) taken on a $SiO_2$ film with thickness equal to 95.0 nm deposited from $SiH_4$+$O_2$ at 425 $^oC$. The angle of incidence varies between 08 $^o$ and 50 $^o$, (**b**, center): Real part of the refractive index and (**c**, right): Imaginary part calculated from spectra at various angles.*

Moreover, the Si-O-Si angles distribution was calculated for $SiO_2$ films deposited from TEOS vapors at temperatures varying between 650 and 820$^o$C. It was suggested that in $SiO_2$ films exist Si-O-Si chains similar to those that exist in the bulk material (bulk-like bridges) and others attributed to chains located near grain boundaries and interfaces (boundaries-like bridges). For the former the Si-O-Si angles are smaller than for the latter. In *fig. I.4.2* the Si-O-Si angle distributions for a TEOS deposited film at 710$^o$C before and after annealing at 950$^o$C are shown. It can be observed that the population of bulk-like bridges (symbolized with T4) increases with annealing and this is connected with the improved electrical properties of annealed TEOS films.

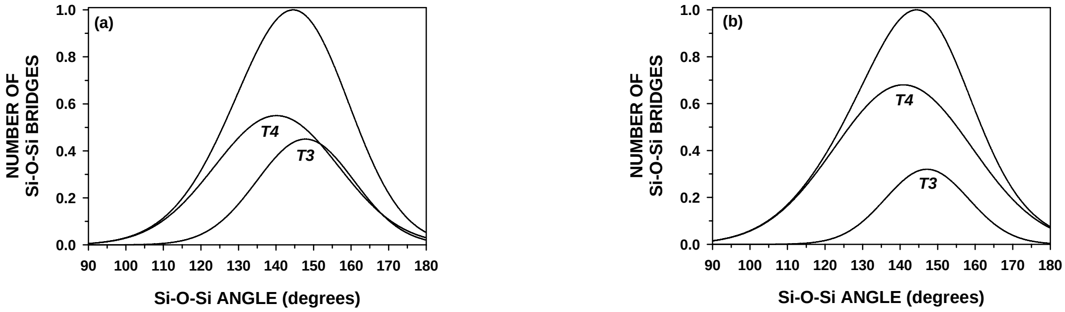



***Fig. I.4.2:*** *Normalized Si-O-Si angle distributions (in arbitrary units) in TEOS $SiO_2$ films as deposited (**left**), and after annealing at $950^oC$ (**right**).*

## b) CVD of $SnO_2$

*C. Favre*

This activity is related to the atmospheric pressure CVD of $SnO_2$. A new APCVD reactor has been installed for the deposition of $SnO_2$ films from $SnCl_4$ vapors and the investigation of the capabilities of this tool (film uniformity, doping, etc) are under investigation. Another subject under investigation is the reversible changes observed in the resistivity of $SnO_2$ films (when activated with some gold mono-layers) as a function of their chemical environment. Gas-sensing configurations based on $SnO_2$ films deposited with this system are shown in *fig. I.4.3.*

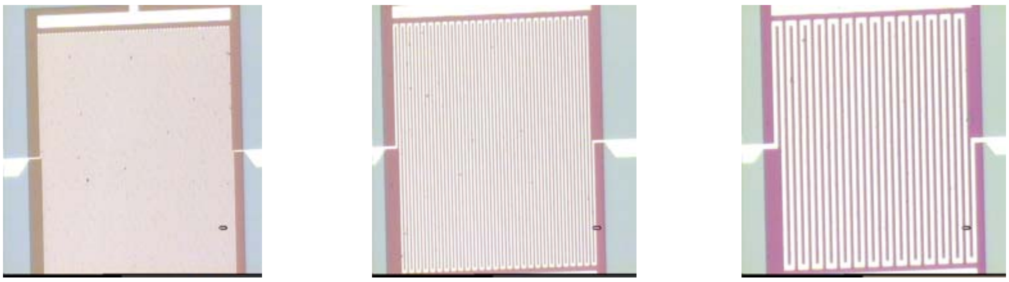


***Fig. I.4.3:*** *Gas sensors formed by depositing the heating element on a patterned $SnO_2$ film. The heating elements have line widths of 2 (**left**), 4 (**center**) and 6 µm (**right**).*

## c) Local formation of $Cu_2O$

*G. Papadimitropoulos*

The oxidation of Cu lines with nano-dimensions to form locally a $Cu_2O$ dot is a very interesting subject since this last is a p-type semiconductor and the oxidation proceeds at relatively low temperatures. So, a locally oxidized Cu line is an n-p-n structure. A gate effect in such structures has been demonstrated. Moreover, the $Cu_2O$ films obtained by oxidation of vacuum evaporated Cu layers were characterized with various spectroscopic methods (X-ray diffraction, FTIR, and spectroscopic ellipsometry I). *Fig. I.4.4* shows transistors based on $Cu_2O$ and *fig. I.4.5* shows typical I-V characteristics of these transistors.These transistors were stable with time.

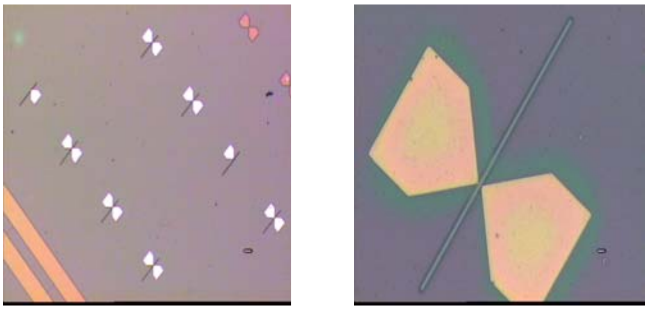


***Fig. I.4.4:*** *Cu-$Cu_2O$-Cu transistors formed by oxidizing the central part of a Cu structure shown in the photos. The whole configuration was covered by a photoresist on which a trench was formed to allow for the oxidation of the uncovered Cu film.*

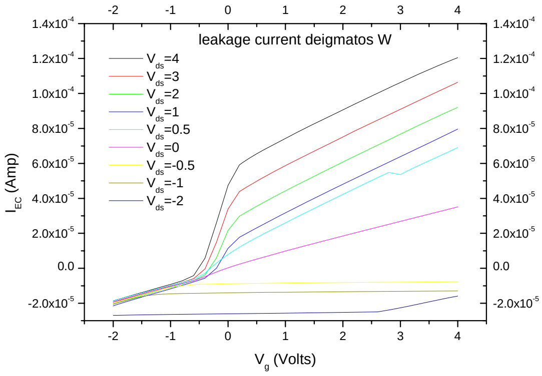



***Fig. I.4.5:*** *Typical I-V characteristics taken on Cu-$Cu_2O$-Cu transistors.*

## d) Smart materials

*V. Vamvakas, V. Assimakopoulos, Y. Aspiotis and D. Pappas (with the contribution of M. Vassilopoulou in device fabrication)*

$WO_3$ films may be doped reversibly when in contact with an electrolyte and under an electric field. This reversible doping implies significant changes in their optical and electrical properties, which can be used in applications such as in displays and in gas sensors.

$WO_3$-based displays have been shown in the past. The reversible changes of color in $WO_3$ films are accompanied with reversible changes of their electric resistance. Therefore, these films may be used for the fabrication of resistive gas sensors. The integration of a display and a gas sensor, both based on the same $WO_3$ film on the same substrate is under development.

$WO_3$ films may also be used for the stabilization of proteins which depends on the doping of $WO_3$ films. In *fig. I.4.6* the adsorption of RgG, assayed with fluorescein-labeled antirabbit IgG antibody, on colored (left) and bleached (right) $WO_3$ strips using fluorescence microscopy is shown. It can be seen that the proteins are preferentially stabilized on the bleached material. The stabilization of proteins on $WO_3$, except of doping, also depends on pH as shown in *fig. I.4.7*.

***Fig. I.4.6:*** *Adsorption of RgG on colored* ***(left)*** *and bleached* ***(right)*** *$WO_3$ strips. For the colored strips the photoluminescence intensity is almost equal on the strip and on the glass substrate* ***(left photo)****. The photoluminescence intensity on the bleached strips is much higher than on the glass* ***(right photo)****.*

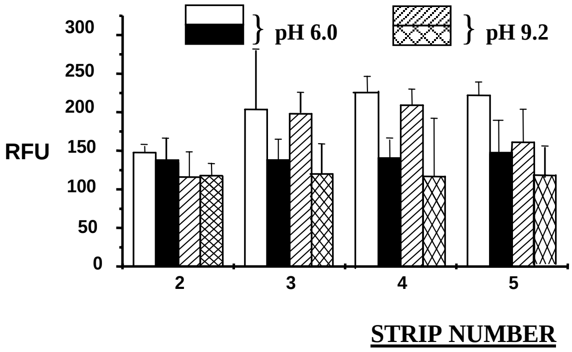



***Fig. I.4.7.*** *Photoluminescence density measured at two different pHs on a colored (doped) (2), two uncoloured (3, 4) and a colored and bleached (5) strip. The error bars were obtained from many measurements taken at various locations on each photograph.*

Within the same activity silicones used in a variety of applications ranging from the encapsulation of solar cells to micro-systems are under investigation. Applications in the above fields are under development.

## Publications in International Journals


1. Comparison of FTIR transmission spectra of thermally and LPCVD grown by TEOS pyrolysis, $SiO_2$ films V. Em. Vamvakas and D. Davazoglou. *Journal of the Electrochemical Society* Vol. 151, 93 (2004)
2. "Fabrication of very fine copper lines on silicon substrates patterned with PMMA via selective chemical vapor deposition" D. Davazoglou, I Raptis, A. Gleizes and M. *Vassilopoulou, Journal of Vacuum Science and Technology B* Vol. 22, 859 (2004)
3. "Optical properties of $SiO_2$-$TiO_2$ sol-gel thin films" P. Chrysicopoulou, D. Davazoglou, C. Trapalis and G. Korda**s** *Journal of Materials Science* 39 (8): 2835-2839 (2004)