## PROGRAM I
## MICRO and NANOFABRICATION

### Project: I. 4: THIN FILMS by CHEMICAL VAPOR DEPOSITION (CVD)

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Paul Sherrer Institute, Laboratory for Micro- and Nanotechnology, Switzerland, (Dr. V. Auzelyte, Dr. H. Solak)

**Projects Running:**

- Novel photovoltaic panels with vertical positioning of concentration Si cells, (FOCUS) (PAVET)
- Optical Smoke Detectors (OAKA) (PAVET)

**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 2008**

**A. Fabrication of planar Copper electrodes by Selective Metal-Organic Chemical Vapor Deposition (SMOCVD)**

G. Papadimitropoulos

Copper films were deposited on Si substrates covered with TiN and patterned with AZ3214$^{TM}$ photoresist to form planar interlacing electrodes as in Fig. 1. The deposition of Cu was made selectively on the exposed regions of the TiN layer only and not on the AZ3214$^{TM}$-covered regions (see Fig. 1, left). After Cu deposition the PMMA was removed in acetone under ultrasonic agitation (Fig. 1, right) and the fabrication sequence was finished by reactive ion etching the TiN using the Cu features as hard mask. A novel chemical vapor deposition reactor was used using as precursor hexafluoroacetylacetonate Cu(I) trimethylvinylsilane (CupraSelect®), which is liquid at room temperature and which was directly injected into the reactor with the aid of a direct-liquid injection system using $N_2$ as carrier gas.

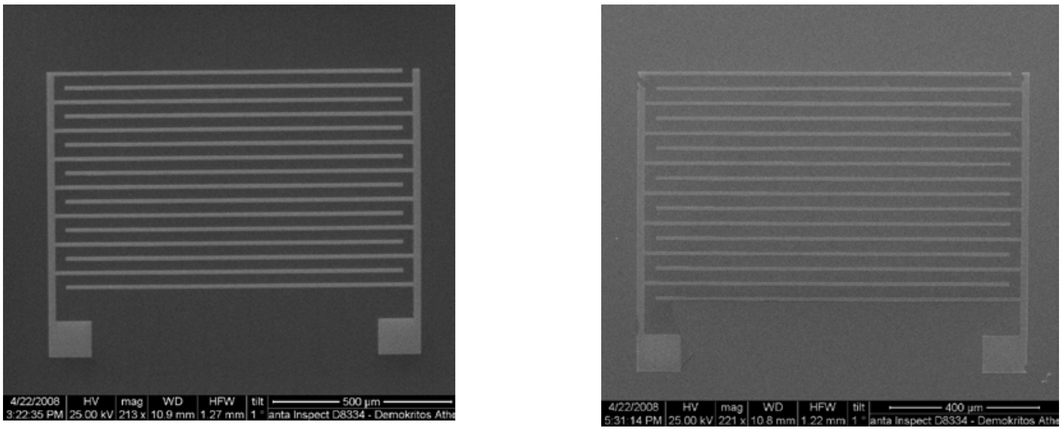


Fig. 1. SEM micrographs of a couple of interlacing electrodes formed on a TiN covered Si substrate by patterning a AZ5214$^{TM}$ photo-resist layer followed by SCVD of Cu at 120 $^{o}$C before (left) and after (right) photo-resist removal.

After the above initial results obtained using optical lithography and with the aim to decrease the dimensions of the obtained features, electron beam lithography was used. TiN covered Si substrates were covered with a 300 nm thick layer of poly-methyl-methacrylate (PMMA), which was patterned with e-beam lithography. After patterning Cu was again deposited selectively on the regions of the substrate that were uncovered by the PMMA. Depositions were carried out within the temperature range 100-150 $^{o}$C and they were proved to be selective in all cases (see Fig. 2). After deposition the PMMA was removed in acetone and under ultrasonic agitation (Fig. 3). Cu lines with dimensions down to 100 nm and separated by gaps down to 300 nm were obtained as seen in Fig. 3. In all cases the adherence of the Cu layer on the TiN substrate was very good. The fabrication sequence was finishing by the removal of the TiN layer by reactive ion etching using the Cu as hard mask.

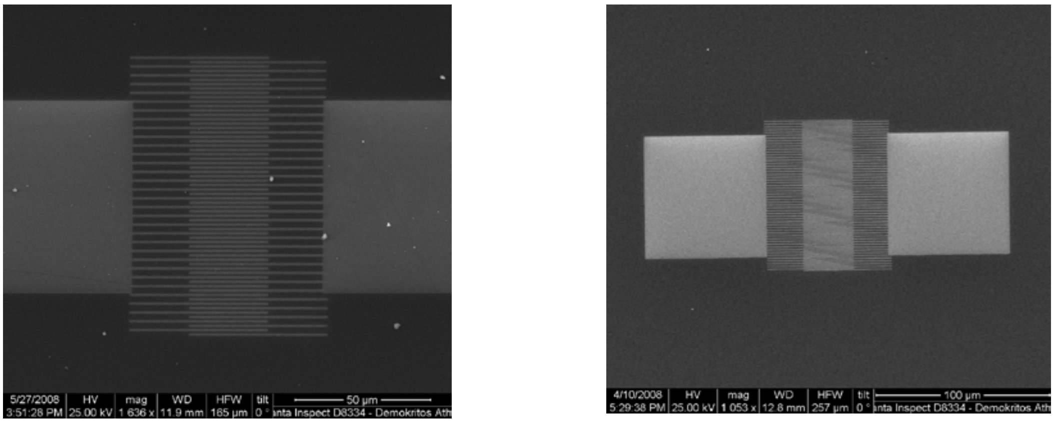



Fig. 2. SEM micrographs of interlacing electrodes formed on a TiN covered Si substrate by e-beam patterning a PMMA layer followed by SCVD of Cu at 100 (left), 120 $^{o}$C (right). Micrographs were taken before removing the PMMA layer.

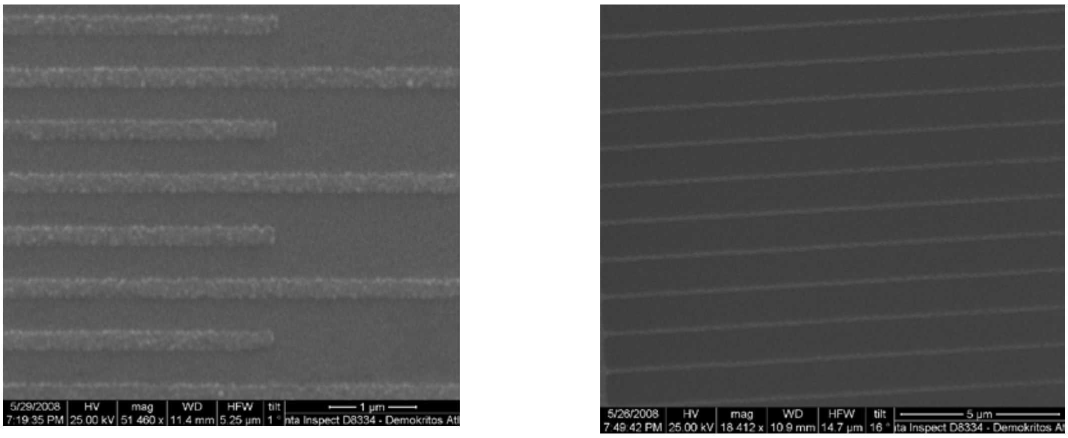



Fig. 3. SEM micrographs taken on electrodes fabricated by SCVD after PMMA removal. (left) Cu lines 200 nm wide separated by spaces of 300 nm, Cu deposited at 100 $^{o}$C. (right) 100 nm Cu lines/1 μm spaces at 140 $^{o}$C.

**B. Fabrication of planar ultra-fine Copper lines with length to width ratio of the order of $10^5$ by Selective Chemical Vapor Deposition**

G. Papadimitropoulos

The advent of nano-technology has created new needs for interconnects with dimensions much longer than the active area of nano-devices. In an effort to obtain long Cu lines with widths in the nano-scal and also separated by fin gaps, we have used interference X-ray lithography. In Fig. 4 Cu lines as long as 1 mm are shown obtained by SCVD as described in the previous section. It an be observed that Cu lines are continuous with no defects and homogeneous.

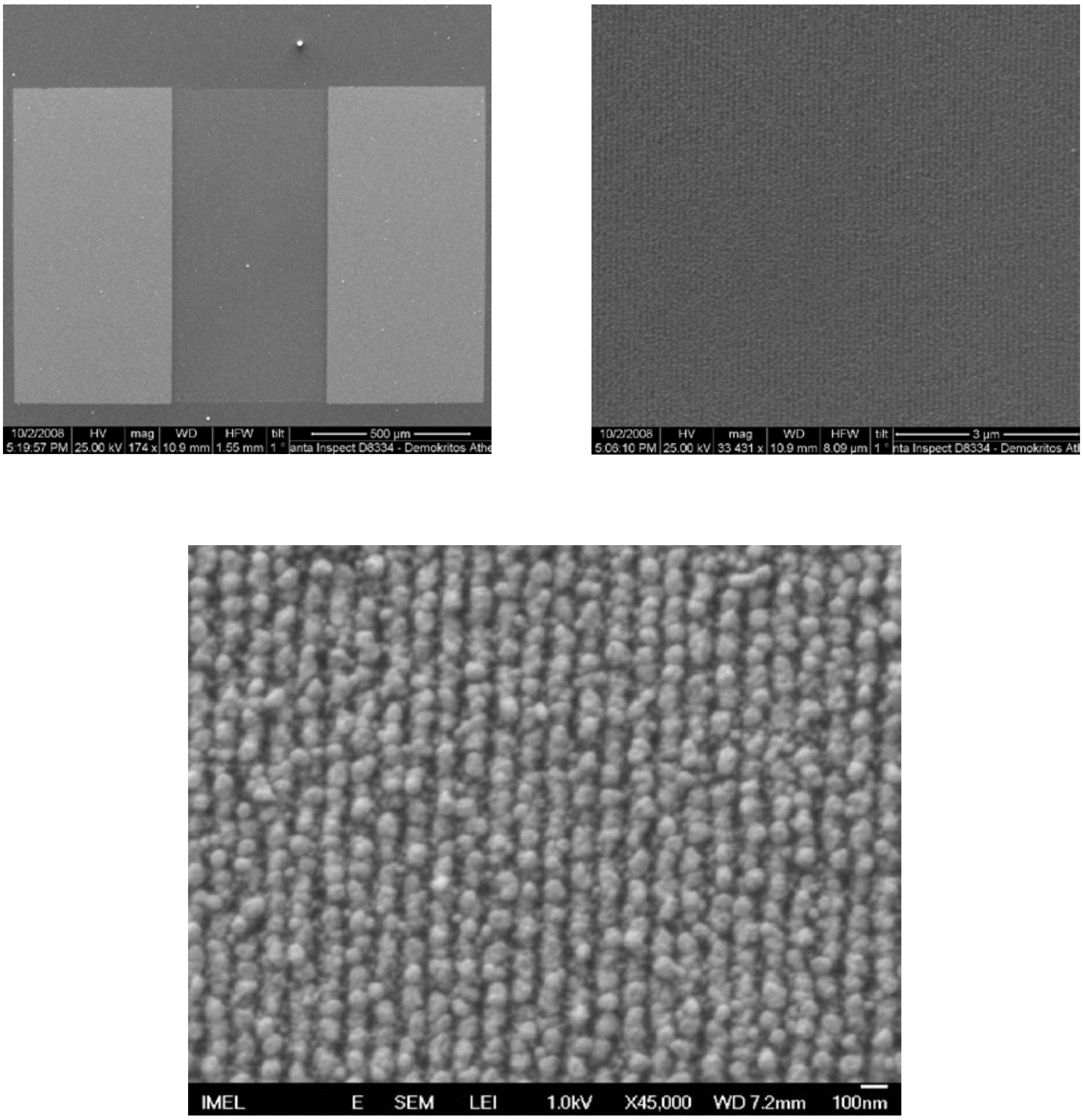
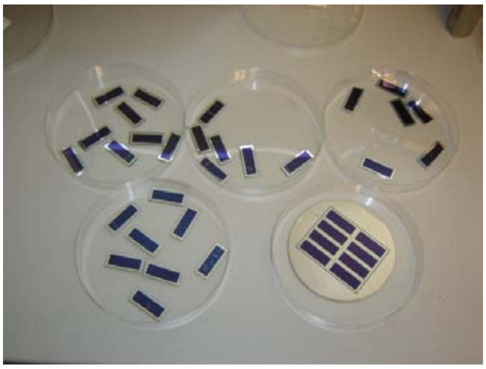



Fig. 4. 1 mm long Cu lines with width of the order of 50 nm obtained by X-ray inreference lithography and SCVD. A general view of the pattern is seen left. Two the lines are formed between the two pads seen left and right. A closer view is seen right and an even closer one down.

### C. Silicon Solar Cells

L. Zambelis - G. Aspiotis

Within the frame of the project FOCUS concentration PV cells were fabricated (Fig. 5). These cells were made on floating zone, low resistivity, Si substrates and exhibited an efficiency of approximately 16% (Fig. 5).



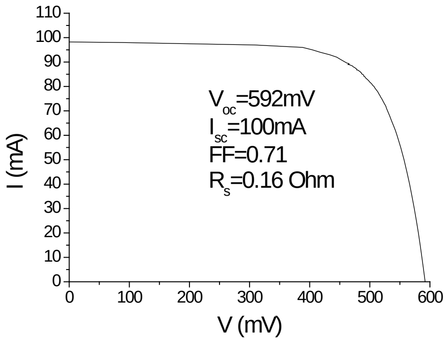



Fig. 5. A view of concentration PV cells made on Si (left) and a typical I-V characteristic taken on one such cell.

PV panels were fabricated by placing the above cells vertically as seen in Fig. 6 in an effort to minimize the space occupied by cells and, therefore increase the reliability by shortening the interconnects between cells, thus forming the FOCUS prototype.

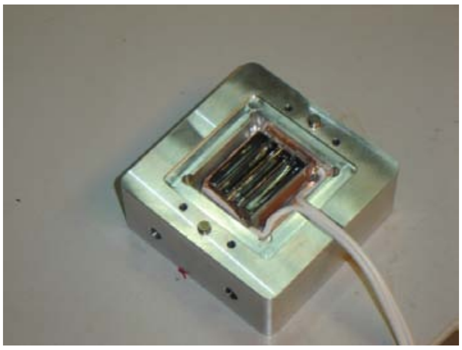


Fig. 6. The FOCUS prototype just packed (left) and before positioning on the optical system for solar light concentration (right).

The FOCUS prototype produced 30 W peak of electricity (3V, 10A) under illumination of 100 suns.

**D. Non-imaging optics for the concentration of light on Si PV Cells**

G. Aspiotis

Non-imaging lenses were designed for use in solar PV cells applications. Many configurations were designed and realized using poly-dimethyl siloxane (PDMS) as shown in Fig. 7. The effort was focusing on the realization of lenses with small focal length and being able to operate with high incident angle tolerances in order to minimize sun-tracking requirements.

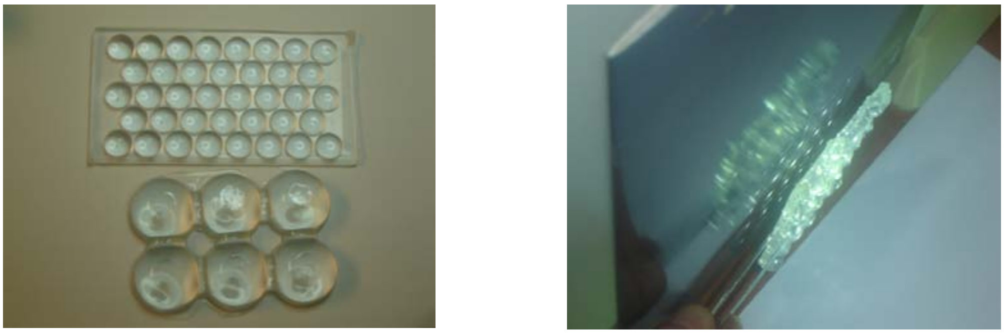


Fig. 7. Various configurations of concentrating systems with small focal length fabricated with PDMS.

Small area (0,5 $cm^2$) Si PV cells were fabricated and were interconnected as shown in Fig. 8. The operation under sun concentration proved to double the overall efficiency of the panel. It was demonstrated then that it is possible to decrease the consumption of single-crystalline silicon on solar panels, which sets the lower limit for the cost of the produced electricity.

Fig. 8. A solar PV panel containing 6 small area (0,5 $cm^2$) Si PV cells operating under illumination of 20 suns.

## E. Optical smoke detectors

G. Aspiotis

Generally, optical smoke detectors contain a light source and a detector arranged in such a way that the light emitted by the former does not reach the latter directly. The presence of smoke particles in the ambient of the system causes light scattering so, in this case, the scattered light reaches the detector and an alarm signal is generated. Within the frame of the OAKA project many configurations operating as described above were designed using commercial software and the corresponding configurations were fabricated and tested using various materials such as poly-dimethyl siloxane (PDMS) as in Fig. 9.

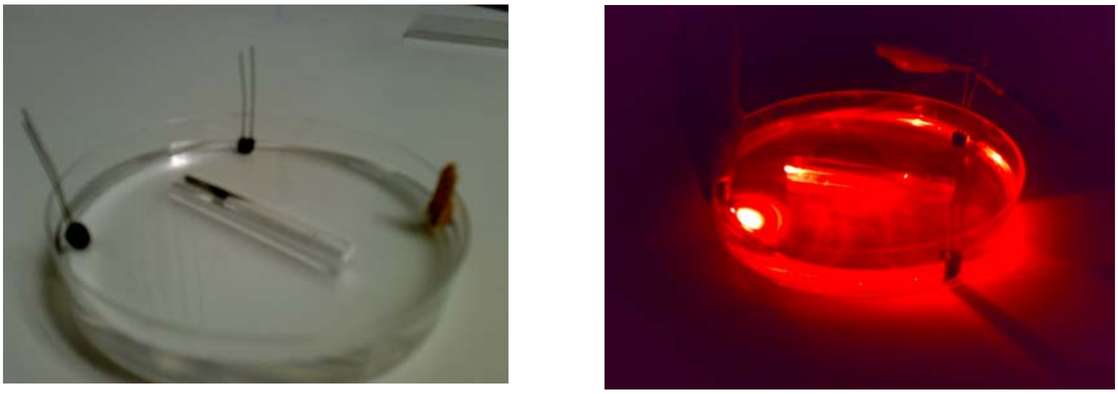


Fig. 9. An optical smoke detector containing one red light source and two detectors made of PDMS.

Other configurations tested were based on the guiding of IR irradiation through optical fibers from the IR source to the detector(s) through the smoke detection chamber (see Fig. 10). Various materials were tested such as PDMS (Fig. 10, left) and poly-amide (Fig. 10, right). In all cases the fabricated devices were operating properly with power consumptions of the order of 1 mW.

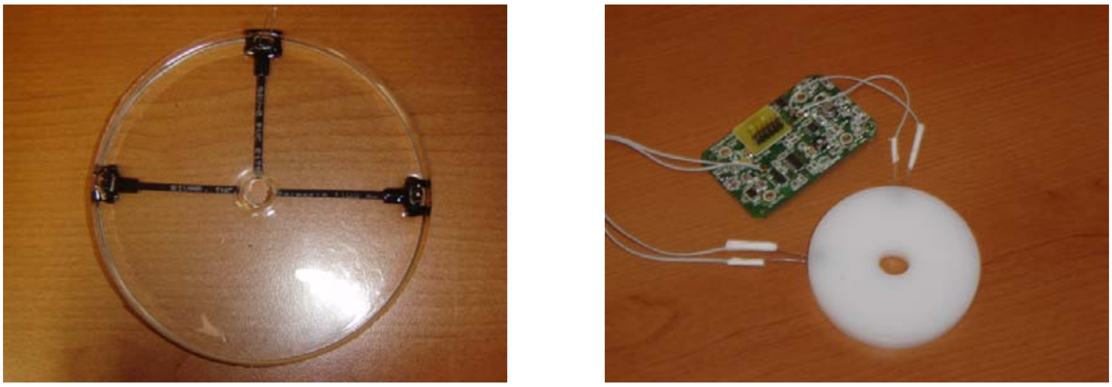


Fig. 10. Optical smoke detectors operating with light guiding from the source to the detectors through the smoke detection chamber. Two detectors are used (left) for the device made of PDMS while one detector is used on the device on poly-amide seen on the right.

## Publications in International Journals and Reviews

1. Flexible $WO_3$ based electrochromic displays using proton conducting solid electrolytes, M. Vasilopoulou, P. Argitis, G. Aspiotis, G. Papadimitropoulos and D. Davazoglou *Physica Status Solidi (C) Current Topics in Solid State Physics* 5 (12), 2008, pp. 3868-3871.

2. Hot-wire CVD of copper films on self-assembled-monolayers of MPTMS G. Papadimitropoulos, A. Arapoyanni and D. Davazoglou *Physica Status Solidi (A) Applications and Materials* 205 (11), 2008, pp. 2607-2610

## Conference Presentations

1. Initial stages of thermal and hot-wire assisted CVD Copper growth on SiLK® and LTO activated with Mercaptopropyl triethoxysilane self-assembled monolayers G. Papadimitropoulos, T. Speliotis, A. Arapoyianni and D. Davazoglou, MAM 2008 -- Materials for Advanced Metallization Conference, Dresden (Germany), 2-5 March 2008

2. Selective CVD of Copper on TiN Substrates versus electron beam patterned PMMA by DLI of CupraSelect® G. Papadimitropoulos, S. Cibella, T. Speliotis, R. Leoni, D. Davazoglou, Micro- and Nano-Engineering (MNE) Conference, Athens (Greece), Sept. 15-18, 2008

## Conference Participation

**1.** MAM 2008 -- Materials for Advanced Metallization Conference, Dresden (Germany), 2-5 March 2008

**2.** Micro- and Nano-Engineering (MNE) Conference, Athens (Greece), Sept. 15-18, 2008