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Fabrication Of Microstructures
Fabricación de Microestructuras

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***Abstract* - One of the education challenges in microelectronics is to convey students the basic steps for electronic devices fabrication. This article introduces how rapid prototyping of planar coils combines photo-mask fabrication, photolithography and wet etching, and how it can be used for training at the undergraduate level. Low cost photo-masks are generated using printing master layouts of coil patterns designed with Inkscape and Adobe InDesign and transferred onto a photographic KODAK paper using a DeVere reduction copy camera. Three parameters are analyzed for transferring the layout onto the photomask and then onto an Al substrate: the camera's reduction factor, the grain size of the Kodak paper and the quality of the InkJet photo-printer. Fabrication of submicron aluminum coils is achieved with optimization of these parameters. The hands-on experience on device fabrication impacts the students' ability to comprehend interactions between mask designs, fabrication and devices layout.**

***Key Words* - Planar coils, photo-reduced camera, transparency photo-mask, education.**

***Resumen* - Uno de los desafíos de la educación en microelectrónica es transmitir a los estudiantes los pasos básicos para la fabricación de dispositivos electrónicos. En este artículo se explica cómo el prototipado rápido de bobinas planas combina fabricación a partir de foto-máscaras, fotolitografía y grabado húmedo, y cómo puede ser utilizado para la formación a nivel de pregrado. Las foto-máscaras tienen bajos costos y se generan con diseños e impresión de patrones helicoidales diseñados usando Inkscape y Adobe InDesign, calcando en un papel fotográfico KODAK y haciendo uso de una cámara reductora DeVere. Tres parámetros son analizados para la transferencia de las geometrías en la fotomáscara y sobre un sustrato de Aluminio: factor de reducción de la cámara, el tamaño de grano del papel Kodak y la calidad de la foto-impresora de inyección.**

La fabricación de bobinas de aluminio submicrométricas se logra con la optimización de estos parámetros. La experiencia práctica en la fabricación del dispositivo afecta la capacidad de los estudiantes para comprender las interacciones entre la máscara, fabricación y diseño de dispositivos.

***Palabras Clave* - Bobinas planas, foto-reducción, Transparencia foto-máscara, Educación.**

I. Introduction

Expensive tools and materials are used in the manufacturing of microelectronic devices (ITRS, 2012), following the miniaturization trends, factories have relied on the scalability provided by the fabrication of costly chrome mask multi sets. Therefore, it is a challenge to find lower cost alternatives to introduce device manufacturing concepts into educational experiences for undergraduate students. An additional challenge is to determine adequate protocols to operate low-cost equipment.

This paper focuses on alternative methods for generating planar patterns with the goal of creating inexpensive and rapid prototyping microstructures. With this purpose in mind, we followed the conventional approach of printing patterns onto transparent sheets. First, the patterns are designed with standard CAD tools and printed on three types of photographic paper: photo glossy, Propalcote C1S® and photo calcium matte paper. Second, patterns are printed using a desktop high quality printer. The quality of the printed figures allowed us to determine the most suitable paper for the optimum transfer of microstructure master patterns. Third, the patterns were copied on resin coated photo transparencies, which can create negative copies from a positive print. Fourth, the method allows for the fabrication of planar quad and round coils on Al coated glass. Fifth, the pattern transfer's dimensions were verified with an optical microscopy.

This method is based in NIST[2] pattern line width standard.

The procedure described help students to understand the micro pattern generation process. This process is attractive for the fabrication of sensors, security stamps manufacturing, micro circuits and electromechanical systems all fields of growing interest in Latin America.

[1] Producto derivado del proyecto de investigación "Fabrication Of Microstructures". Presentado por el Grupo de Investigación Centro de Microelectrónica de la Universidad de los Andes.

[2] NIST: National Institute of Standards and Technology

The method used is cost-effective and can be used for early training on submicron fabrication.

II. Pattern generation

Figure 1 describes the complete master process from the master pattern design to its definition on Al glass slide substrate.

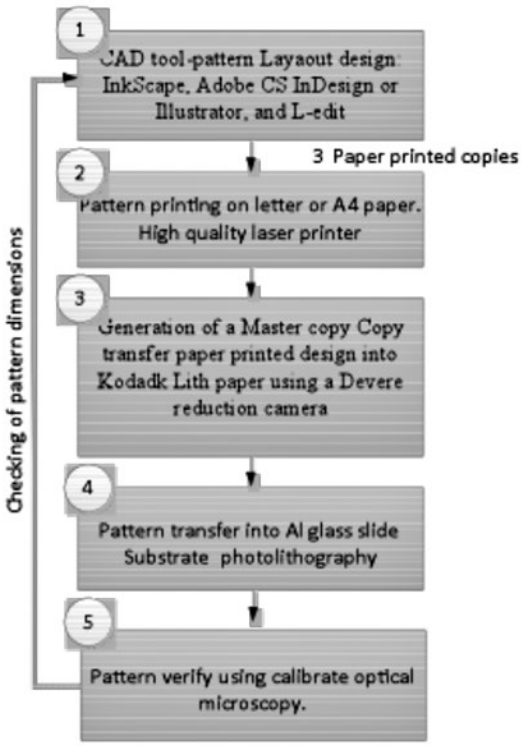

Fig. 1. Micro pattern genertion process.

The steps to the patent layout process are:

-Pattern design: The pattern layout can be created from a series of vectored programs such as InkScape, Adobe CS InDesign or Illustrator, or L-edit. The software does not limit the work space but pattern sizes are limited by the maximum design area copy camera (15"x20").

-Pattern prints: the layouts are printed onto photographic paper with a commercial high resolution printer at a reproduction size 1:1. The master paper copies were printed using a Samsung LaserJet printer at its full capacity: 1200dpi resolution and the maximum contrast. The paper selection defines the quality of the masks, three copies 8,5"x11" were printed onto: glossy paper, Propalcote C1S® paper and photo calcium matte paper.

-Pattern reduction: to transfer the layout into the master photo mask, a photo freestanding copy camera is used. It can accommodate formats up to 8"x10". A light sensitive KODAK Ortho Films 2556, type 3 (KP, also known as a lith film) is exposed to light radiated from the table copy lights. Lith paper is a high contrast photographic film composed by a thin layer of visible light sensitive photoresist, on top of a transparent acetate film (Wade, 1983) (KODALITH, 2001) . It is commonly found at any photo stores. It is used for the fabrication of photo masks. This also the KP film was cut to the final photo mask format in a dark room (Banqiu, 2005).

-Exposure: Exposure and developing times for the KP film will be described below. By combining high resolution dpi capability with high photographic film quality, the copied patterns turned out sharper and finer.

- Patterns transfer onto Al glass slides: the developed KP film acts as the master photo mask during a photolithography process to generate replicates of the mask patterns onto Al coating on glass substrates application etching over coating on glass.

In all the steps described above, visual inspection (by optical microscopy) was applied to track the differences between the layout dimensions, the paper printed-master mask and the patterns on the substrate.

A. Photomask fabrication using a reduction copy camera

A DeVere 480 camera allows the reduction of the print on paper patterns onto the KP film. Figure 2 displays its main components: the adjustable baseboard table, the copy lights and the adjustable camera body with manual focusing hand wheels.

In a dark environment, the camera position is secured at 45 cm and the KP films are placed under the reflex mirror, aligned into the maximum illuminated area. The master prints on high resolution paper are located on top of the baseboard table and fixed with masking tape.

Figure 3 shows a planar master pattern design on Adobe InDesign CS5 and printed on Calcium matte paper.

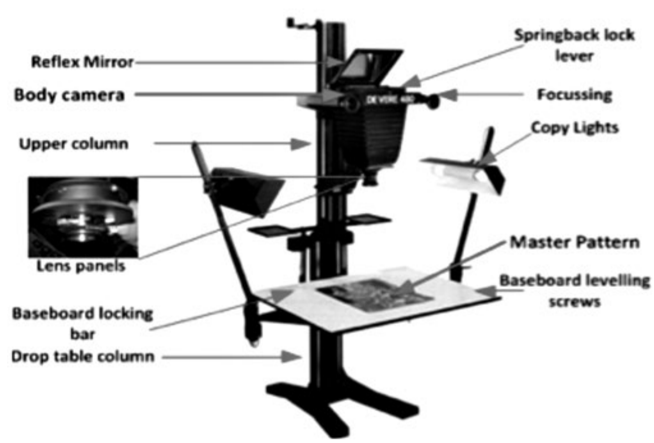

Fig. 2. DeVere 480 camera parts (Wade, 1983) (DEVERE, 2005).

The designed layout integrated: planar quad, round coils, square and round arrays and an array of parallel lines with different separations and dimensions. The lines were drawn based on the Photomask Line width Standard: The Standard Reference Material 2059, established by The National Institute of Standards and Technology (NIST) –Agency of the U.S. Department of Commerce (Potzick, 2008) (Avila, 2011).

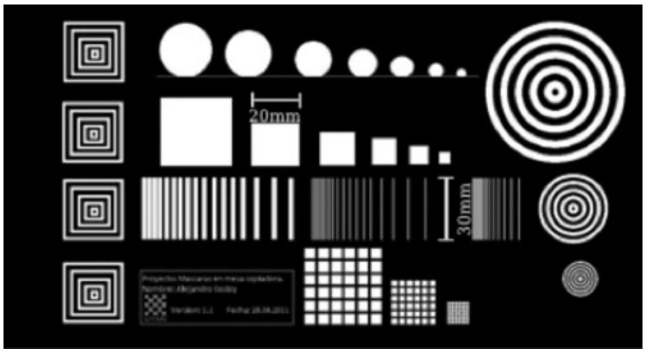

Fig. 3. Pattern design on Adobe InDesign CS5 and printed on Calcium matte paper.

Two independent 13W lamps are placed at both sides of the baseboard table. The lamps have an adjustable head angle, allowing for the maximization of the illumination area on the printed layout. The lamps were characterized with an Ocean Optics USB4000 spectrometer. This was located at 1 meter distance from the lamp and the lamp's absorbance was recorded, see figure 4.

Two absorbance peaks are visible: at 540 nm and at 620 nm, which correspond to green and yellow wavelengths (Mosca, 2004).

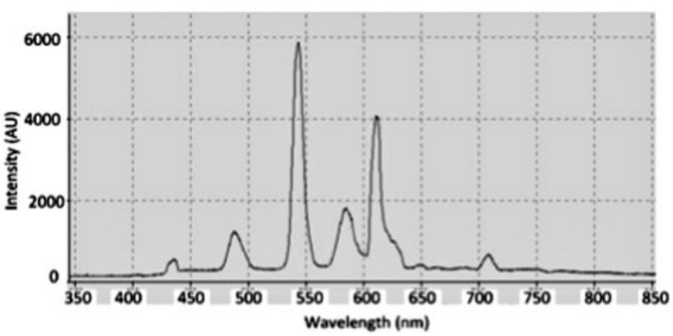

Fig. 4. Absorbance characterization spectrum of a copy light.

A reduction factor test was carried out to identify the optimum positions for the camera body (the lens panel positions) and baseboard heights, aiming to fabricate planar microstructures (~25um).

B. Reduction factor test

The reduction factor was determined by comparing the patterns dimensions on the KP film and the master layouts. The camera was focused using a magnifying 60x eye. The KP films were exposed for 25 seconds at different lenses and base board table separations. The developing time was defined in a sensitometry test to trace down the relationship between pattern dimensions on the KP film and the development time. By immersing the sample into 1:4, photo developer, DI water solution for 1 min, next rising with DI water stop-bath for 10s, finally it is immersed into 1:4 fixer, DI water solution to 2 min.

The experimental data for the reduction factor is presented in figure 5. For this test the camera was located at different vertical positions from 15 to 45cm and the baseboard position was varied in steps of 10cm. defined as position 0 (10cm apart), position 1 (20cm apart) and so on, up to 70 cm separation. The maximum reduction factor is achieved for the following position settings: camera lenses at 45 cm and layout baseboard at position 6. The adjustment is better done when using a magnifying glass changing the height of the lens in order to have the best reduction at the exact focal point.

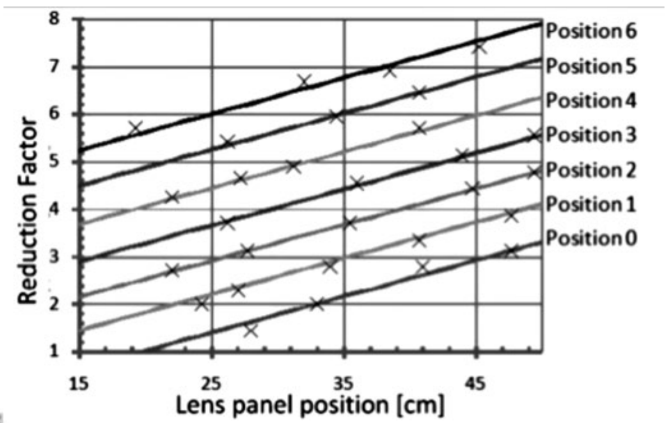

Fig. 5. Experimental reduction factor determined as a function of the camera lenses and baseboard vertical position on the free standing copy camera. The position 6 and 0 represents the maximal and the minimal separation distances correspondingly.

V. Results

A. Photo paper selection

The copies of the pattern layout were printed on a Samsung Laser jet printer and subsequently a photo mask (on KP film transparency) was generated from each individual print. Optical microscope mask images for the best defined individual patterns were examined with the image processing tool box from Image Processing Matlab Toolbox, see figure 6 (only the analysis for the mask generated from the Calcium matte paper layout is presented, although all papers were analyzed). Cross sections were extracted from the original images to analyze the images' contrasts.

The image and the outcome of the analyses showed that photo calcium matte delivered the best contrast-resolution for Photomask linewidth Standard developed by NIST.

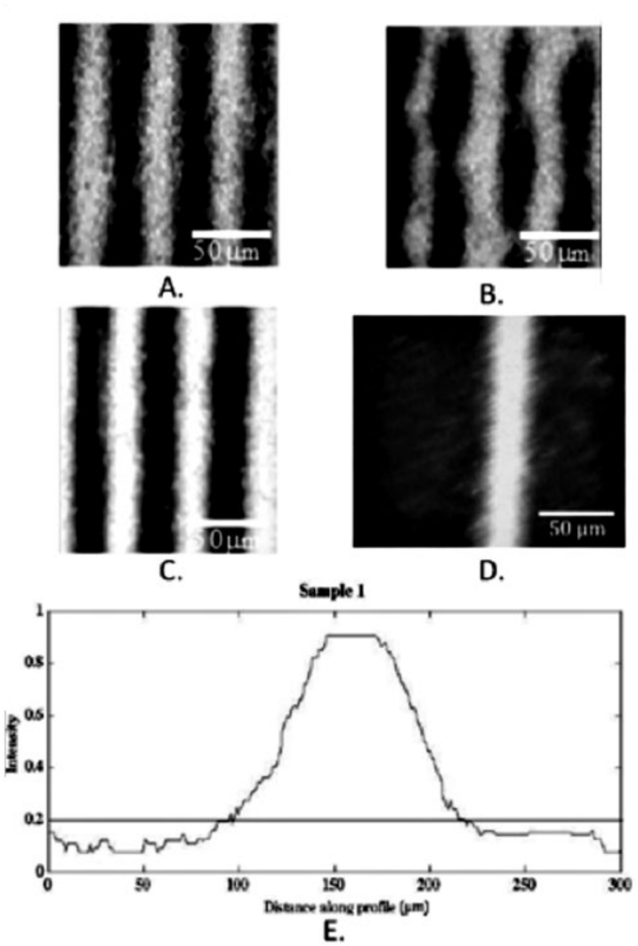

Fig. 6. Optical Microscopy images of the photo mask obtained with a Olympus CX21 and Patterns generated from. A) Photo glossy paper. B) Propalcote paper. C) Photo calcium matte paper. D) Optical image of one of the NIST standard reference. E) Corresponding intensity cross section profile [8].

B. Photolithography

The master photomask was tested in a photolithography process to transfer the planar quad and round coils onto 100nm Al coated glass. The substrates were spun coated with 2 um of a SC1827 positive resist. Photo Patterning resist is performed using Aligner Karl Suss MJB-3 Mask Aligner running in contact mode. The photo mask and the resist coated substrate were aligned and exposed to UV (λ= 400 nm @ 15mW/cm^{2}for 1 min). The exposed resist areas were soluble in MF319 for 2 min. The Aluminum coating uncovered by the developing was then etched by Tetramethylammonium hydroxide at 3.5% and the protecting resist is removed with the PR1000 solution (Rai-Choudhury, 1997), (Franssila, 2010).

1. Submicron 25µm coils

Etched patterns were submitted to visual inspection and microstructures quad coils conductive trace: 25µm, permit to estimate the dimensions difference of 7% for each individual master pattern. Figure 7 displays the correspondent photomask a transfer patter on Aluminum.

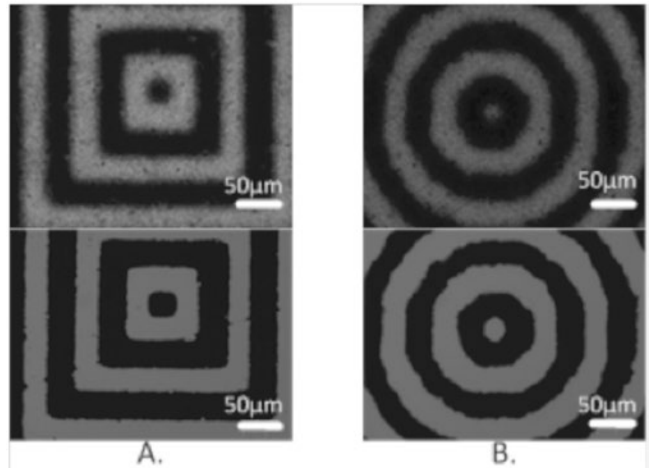

Fig. 7. Fabricated planar coils optical microscopy images. A) (Top) photo mask and (bottom) Al quad coil. B) (Top) photo mask and (bottom) Al round coil.

VI. Conclusion

The methodology for the fabrication of planar microstructures coils has been described integrating a critical step, the generation of the photomask. Photo masks have been created by the combination of CAD tools designs printed on high resolution paper and copied on photo transparencies. The resolution achieved using the designed mask in a photolithography process was 25 µm. The described methodology permits the photo mask generation at effective cost under $50 USD per photo mask, this cost was disposed through standard materials prices and engineer work hour cost.

The etched technique used Tetramethylammonium hydroxide, this technique could be used in other subtract materials as silicon, mica and similar chemical structure. This can be useful to provide hands-on fabrication to undergraduate students, researchers and micro or nanotechnology learners.

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