In the Winter 1999 issue of Nanonotes we are introducing two tools which add exciting new capabilities to the Nanotech Nanofabrication Facility at UC Santa Barbara. Our E-Beam Lithography and Optical Stepper Systems are now available for use by the UCSB and NNUN research communities. Access information and hourly rates for the Cleanroom and E-beam labs are available on-line at http://www.nanotech.ucsb.edu/.

JEOL JBX-5DII(U) E-Beam Writer at UC Santa Barbara
by Ernie Caine

The JEOL JBX-5DII(U) electron beam lithography system at UC Santa Barbara went “on-line” in April of this year. The UCSB Nanofabrication facility provides full maskmaking and nanometer direct write capabilities to Off-campus and UCSB researchers in engineering, physics and materials science communities.

The machine was originally commissioned in 1986 at Cornell University, (at the then named Micro-Research Fabrication Facility, an early predecessor to NNUN). The machine was transferred to UCSB last year as part of the NNUN site “partnership” and is expected to likewise enhance our research capabilities for the immediate future. Fellow NNUN staff members at Cornell (R. Tiberio, D. Costello (now at DuPont), and M. Rooks (now at IBM-Watson) as well as our JEOL counterparts Paul Maker and Rich Muller at JPL have contributed greatly to this successful transition. This complements existing e-beam lithography tools available at the other NNUN nodes: Cornell (LEICA VB6), Penn. State (Leica/Philips EBPG5-HR) and Stanford (Hitachi HL-700F).

The JEOL is a computer-controlled e-beam lithography system capable of writing complex patterns with dimensions down to 30 nm (with appropriate resist/substrate conditions). This high resolution capability, however, places limits on writing speed, field size and pattern placement. The system hardware features an ion-pumped column and chamber with LaB6 electron emitter, 25 and 50 kV column voltages and turbo-pumped chamber and loadlock. Beam current, which directly impacts resist image resolution through the beam diameter, ranges from approximately 50 pA to ten’s of nA’s. This in conjunction with the 2 MHz maximum sweep frequency (0.5 usec minimum dwell time) limits speed thereby extending “write” time.

Exposure samples can be 3 or 4 inch mask plates, 2 or 3 inch diameter wafers or parts of a wafer (piece parts). Piece parts must fall within specific dimensions due to the limited number of sample chucks we currently have available that use sample front surface referencing. Sample window widths that are allowed include 6, 8.5, 10.5, 16 and 21 mm. Stage travel places a limit on the maximum exposable area with Xmax = 100 mm and Ymax = 75 mm. Generally wafers or piece parts are used for direct write applications where the pattern to be written registers to a pre-existing pattern on the substrate. This entails the use of registration or mapping and requires two types of registration marks. Additional information on physical dimensions can be found at the Nanotech website http://www.nanotech.ucsb.edu/.
The JEOL JBX-5DII(U) has proven capabilities:

- Field stitching accuracy: Spec 0.1 \( \mu m \)/Actual 0.038 \( \mu m \) (3-sigma)
- Overlay accuracy: Spec 0.1 \( \mu m \)/Actual 0.053 \( \mu m \) (3-sigma)
- Minimum feature size: ~35 nm for < 100 nm PMMA resist

There are four basic column exposure “modes” resulting from the combination of the 25 and 50 kV column voltages and the two final or deflection lens, known as the 4th and 5th lens. The lowest resolution mode is at 25 kV with the 4th lens which has the machine’s maximum field size of 1600 microns. The minimum beam diameter is ~ 100 nm for 30 pA of beam current. Typical values would be 100 pA to 10 nA. Changing to the 5th lens reduces the field size (and beam step) by a factor of ten to 160 microns and 2.5 nm, respectively. Minimum beam diameter here is ~ 70 nm. 50 kV/4th lens conditions operate with a maximum field size of 800 microns and 25 nm beam step. The last mode, 50 kV/5th lens, has the highest resolution and is used for nanolithography, such as for devices that exhibit quantum effects. Beam currents of 30-100 pA are typical for the 80 micron field size and 10 nm beam diameter. Note that although the machine is capable of doing work at both accelerating voltages, it is generally kept at 50 kV.

Several related areas must be taken into account in doing an exposure, wherein electronically stored “image data” (or patterns) are ultimately transferred to some substrate or work piece with the electron beam. These areas include:

1) **CAD layouts**, from the simplest of a single layer device with no registration to a multi-level design for a mask with registered direct write layers, this is what is written. We primarily use L-Edit from Tanner Research. Whatever CAD used, the final pattern should be formatted in gdsII/Calma. Layers should have a hierarchical structure to keep memory requirements low.

2) **Pattern data conversion** to machine language code. This fractures or ‘parses’ individual pattern layers into fundamental shapes that the machine can work with. The stitched field size must be declared at this time along with the gds layer numbers and pattern size. Also the electron beam current must be determined which in turn fixes the beam diameter and sweep time. (A general rule is that the diameter should be ~1/5 of the CD or smallest feature to be written). Simple pattern manipulations such as tone reversal and mirroring can be done here.

3) **Exposure files** that “direct” the beam and stage. This program, along with a pattern generator, drives the electron optics which combines with x-y servo-locked stage movement to write the pattern. Other information needed here includes: location of registration marks, mark detection parameters, area and line doses and pattern array placement.

4) **Sample preparation** which is primarily a resist coating steps; a resist that will then allow for an image transfer via subsequent additive (eg. metallization) or subtractive (eg. etching) processing. We currently have baseline processes using various PMMA, SAL-601 and EBR-9 resists.

5) **Machine calibrations and sample registration.** This calibrates the working surface for proper field size, correction for rotation and exact location of registration marks. One must provide a layout showing relative spacing and location of marks and relative placement of the exposable pattern center.

6) **Proper exposure conditions and doses.** One generally starts by determining the beam diameter needed, which when combined with column conditions and dose determine the allowable beam currents.

We currently do not have automatic proximity correction software, therefore corrections must be done manually at the CAD stage using the ‘data typing’ option. This is important for pattern features of less than ~3 microns including isolated shapes and gaps.

![Figure 3](image-url) E-Beam defined 0.4 \( \mu m \) line in GaAs etched with Cl2 in Radical Beam Ion Beam Etcher (RBIBE). The mask material was nickel.
Nanotech is a Member of the National Nanofabrication Users Network (NNUN)
Nanotech at the University of California Santa Barbara

Nanotech on the web:  
http://www.nanotech.ucsb.edu/

For information regarding Nanotech at UC Santa Barbara, users can now access Nanotech on the web. Nanotech’s Web Site has up-to-date information about the UCSB Nanofabrication Facility and E-Beam Laboratories. Our new address is http://www.nanotech.ucsb.edu/