

## Chapter 2

### Device Fabrication Process

#### 2.1 : Introduction

Different process techniques are used to fabricate co-planar waveguide (CPW) structures with approximately micron thick conductors. Several approaches are investigated to obtain better yield of the processed devices; these include

- i. Chlorobenzene metal lift off
- ii. Gold electroplating
- iii. PREGOS with image reversal photoresist
- iv. Metal lift off with polyimide

Of all these methods, metal lift off with polyimide turns out to be the best with easy processing steps and maximum yield. Chlorobenzene lift off process is not reliable in terms of getting good lift off and also it requires the use of a potentially hazardous organic solvent, chlorobenzene. Gold electroplating technique has large uncertainty with photoresist adhesion and often results in failure during electroplating. Positive tone reverse gradient of slope (PREGOS) process with image reversal photoresist is not very successful in terms of obtaining negative resist profile. On the other hand, the polyimide lift off process is very reliable and only a few simple additional steps are required.

Besides the fabrication procedures, processed devices are lifted off from their parent semi-insulating substrate onto an alternative substrate with Epitaxial Lift Off (ELO) technique. In the ELO process, a Molecular Beam Epitaxy (MBE) grown thin layer of gallium arsenide (GaAs) is transferred onto a different substrate for improved performance of the devices.

## **2.2. : Chlorobenzene metal lift off**

The Chlorobenzene lift off process is a single-step metal lift off technique with diazo-type photoresist [Hatzakis et al. 1980; Halverson et al. 1982] (such as AZ 1350J). In this process the resist layer is soaked in chlorobenzene and is exposed to ultra-violet light before the development. The chlorobenzene soaking process changes the cross-sectional profile of the developed resist image into an overhanging pattern, which is suitable for metal lift off. Chlorobenzene penetrates to some depth into the resist layer and extracts the residual casting solvent and low-molecular weight resin species. As a result it reduces the dissolution rate of the top resist surface in aqueous alkali developer without affecting the bottom resist layer, making the undercut resist profiles required for successful metal lift off.

The success of chlorobenzene lift off was found to be very much dependent on different process parameters. After careful studies, a process sequence was developed [Cheung 1987] to produce repeatable results, yet the yield was not satisfactory. The process sequence used for chlorobenzene lift off is discussed in detail in the following section.

### **2.2.1 : Preparing the sample**

The samples are usually grown in a Varian Gen II Molecular Beam Epitaxy (MBE), where the epitaxial layers are grown on a semi-insulating substrate with a growth rate of  $\sim 1 \mu\text{m/hr}$ . The doping levels and thicknesses of the epi layers are varied for different samples. During MBE growth the backsides of the samples are mounted to the molybdenum block in the growth chamber with indium (In) metal. To remove this In from back side, the front side of the sample is covered with wax on a glass slide using a hot-plate. The glass slide with the sample is then soaked in In-etchant solution (10:10:1 DIH<sub>2</sub>O:HNO<sub>3</sub>:Non-buffered HF) for  $\sim 1$  minute until all In is gone. The sample on a glass slide is then rinsed in acetone, ethanol and DI water. The sample is separated from the glass slide using the hot-plate again and rinsed successively in acetone, ethanol and DI water to remove wax from the front side.

### **2.2.2 : Lithography**

The lithography process starts with the cleaning of the surface of the sample. Cleaning usually consists of rinsing in acetone with ultrasonic for ~1 minute, followed by rinsing in ethanol and de-ionized (DI) water. To remove any native oxide, the sample is dipped in hydrochloric acid (HCl) for 3-5 seconds followed by rinsing in DI water. Cleaning is followed by dry baking of the sample in a convection oven at 170°C for 20 minutes. An adhesion promoter (Microposit Primer) and a positive photoresist (AZ 1350J or AZ1350J-SF) are then spun on the sample at 4000 rpm and 3000 rpm respectively, each for 30 seconds. The sample is then pre-baked in a convection oven for 30 minutes at 70°C, followed by soaking in chlorobenzene for 10 minutes. The sample is then exposed for 60 seconds in an HTG UV-lamp mask aligner at a wavelength of 370 nm with a constant intensity of 2.2 mW/cm<sup>2</sup>. The contact pressure between the sample and the mask is maintained at 7 - 8 mm of mercury. The sample is then developed in an aqueous alkali-type developer (Shipley Microposit Developer 452) for approximately 2 minutes under mild agitation. At the end of development, the resist pattern on the sample is examined under a microscope.

### **2.2.3 : Metallization**

Metallization is done in a vacuum system at a pressure of around  $5 \times 10^{-6}$  Torr. The metal scheme usually used is a thin layer of chrome, followed by thick silver and a final layer of gold. A chrome rod is used to thermally evaporate the chrome metal of approximately 200 Å of thickness with a deposition rate of ~ 4-6 Å/sec. One micron thick silver is deposited from silver pellets using the e-gun evaporator with a deposition rate of 20-40 Å/sec. Gold is again thermally evaporated from gold wires to a thickness of ~500 Å at a rate of 4-6 Å/sec. The thicknesses are measured during the deposition with an Inficon crystal thickness monitor.

#### **2.2.4 : Discussion**

The chlorobenzene metal lift off technique had a yield of only 30-40%. The repeatability performance was also very poor. Above all, exposure to chlorobenzene is a health hazard. Its exposure can cause nausea, dizziness, headaches and damage to liver and kidney. Among its chronic effects, it is also possibly a carcinogen [Chlorobenzene ]. These drawbacks prompted the investigation of other processing techniques to fabricate co-planar waveguide structures.

#### **2.3 : Gold electroplating**

Electroplating has always been used in the processing area for depositing thick metals. This technique is simple and inexpensive, especially when noble metals are used as the depositing material. Gold electroplating was investigated to fabricate co-planar waveguides, where a thin base metal of chrome and gold are first evaporated on the sample to get electrical connections over the entire sample for electroplating. This is necessary because the epi samples usually consist of lightly-doped materials, which do not provide a good electrical path. As a final step, the thin base metals are etched carefully to get the final device pattern. The detailed processing steps involving gold electroplating are discussed in the following sections.

##### **2.3.1 : Cleaning and lithography**

The surface of the sample is cleaned with trichloroethane (TCA), followed by acetone, ethanol and DI water. The sample is dipped in HCl for 3-5 seconds only to remove any native oxide. The sample is then metallized with thin layers of chrome and gold as a base metal for subsequent gold electroplating. Chrome is evaporated first to get good adhesion between the evaporated metal and the semiconductor surface, and then gold is added for better adhesion between the evaporated and electroplated gold. Both chrome and gold are evaporated thermally in a vacuum system held at a pressure of  $5 \times 10^{-6}$  Torr to a thickness of  $\sim 200\text{\AA}$  each. Following

the thin base metallization, lithographic processing is performed, starting with the spinning of adhesion promoter and positive photoresist on the sample at 4000 rpm for 30 seconds each. For photoresist, both diazo-type (such as AZ 1350J and AZ 1350J-SF) and image-reversal type (such as AZ 5214-E) resists can be used. With either type of resist, the sample is prebaked on a hot block in the convection oven for 60-90 seconds at 85°C-90°C. With diazo-type resist the sample is exposed in a UV-lamp mask aligner (with a wavelength of 370 nm at a constant intensity of 2.2 mW/cm<sup>2</sup>) for 55-60 seconds, while with image reversal type resist, the sample is exposed for 15-20 seconds at the same ultra-violet intensity. The sample is developed in the aqueous based developer for 1-2 minutes, till a clear and distinct pattern is visible. For the diazo-type and image reversal type resists, the developers used are Shipley Microposit Developer 452 and AZ Developer 425 respectively. The sample is then flood exposed in the UV Aligner through a clear mask for 20 seconds and then post-baked at 125°C for 30 minutes to harden the resist layer.

### **2.3.2 : Electroplating**

The electroplating is performed on a sample with a positive resist pattern (clear areas will be metallized) on the top of thin evaporated base metals, which provide the electrical path within the sample. The electrical arrangements are shown in fig. 2.1, where the one electrode (anode) is made of platinum foil and has an area of same order of magnitude as that of the sample. The sample itself acts as the other electrode (cathode) in the solution. Electroplating depends on the current density and the temperature of the electroplating solution. The electroplating solution used here is Orotemp 24 RC and for this solution the recommended working temperature is 65°C. The current density usually used is 5 mA/cm<sup>2</sup>, which has a deposition rate of approximately 5x10<sup>-3</sup> μm/sec [Wentworth 1990]. Hence the current flow is set according to the area of the electroplating surface. Higher current density produces a rougher electroplated surface. Much higher or much lower temperature also causes the failure of the electroplating in terms of adhesion and removal of photoresist. The polarity of the current source is critical too. Under reverse polarity the process etches gold instead of depositing. The process is carried out under a fume hood since the electroplating solution can evolve a cyanide gas. At the end of electroplating, the

sample is rinsed in DI water to remove remaining electroplating solution and dried to verify the thick resist pattern with the microscope.

### 2.3.3 : Etching the base metal

Before the etching of thin base metals, the photoresist layer, which acts as the mask for electroplating, is removed with acetone. Complete dissolution of resist layer is desired because incomplete removal of all resist may prevent subsequent etching of base metals. Thin base metals of chrome and gold are etched with Chromium etchant (Transene Type 473 ) and Gold etchant (Transene Type A ) respectively. To etch the gold layer first, care should be taken to control the etching rate of the etchant, as longer etching would etch the electroplated gold too. The etchant used has a etch rate of  $30 \text{ \AA}/\text{sec}$ ; therefore, the etching time is only around 6-7 seconds (at room temperature) to etch away all the exposed evaporated gold. The sample is rinsed in DI water to

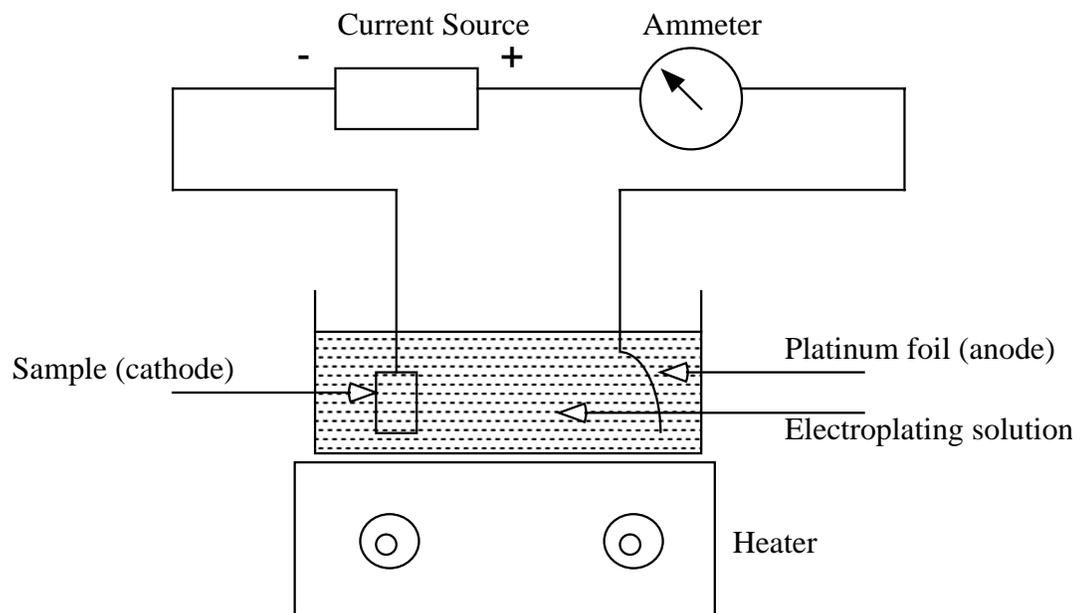


Fig. 2.1 : Electrical arrangement for gold electroplating.

remove all the remaining Au etchant. Immediately after the etching of gold, the Cr layer is etched with Cr etchant at 40°C temperature. Once a native Cr oxide layer is formed, chrome etchant becomes ineffective, and in most cases, a different Cr etchant solution is required. To remove the Cr layer it takes only 10 - 15 seconds. Bubbles are evolved during the etching and end of bubble formation indicates the end of the etching process. If it is found that the chrome layer is not dissolved easily, then the sample is immersed in gold etchant again for a couple of seconds to ensure that there remains no evaporated gold, and then Cr etchant is tried again. It is also found that at a slightly higher temperature (40°C), Cr etchant works much better. After the Cr etching, the sample is rinsed in DI water very thoroughly. At this point, the processing of co-planar waveguide structure is done and is carefully checked under the microscope to determine the line and the gap widths of the devices. Also, with an Alpha Step Profilometer, thicknesses of the electroplated gold is measured and compared against the calculated values.

### **2.3.3 : Discussions**

The success of gold electroplating was found to be strongly dependent upon the adhesion of photoresist on the thin base metal. In case of poor adhesion, the electroplating solution creeps under the photoresist and electroplates the unexposed region not intended for metallization. SEM (Scanning Electron Microscope) photographs taken after such failures verify this poor adhesion of photoresist. A few times when photoresist adheres well, the rest of the electroplating works well, and the chances of achieving good devices on that sample are also very high. For better adhesion of photoresist, evaporating only a chromium layer was also tried, but in that case electroplated gold does not stick to the evaporated metal properly. A recent study implies that a thin layer of nickel on top of chromium works very well in terms of adhesion of photoresist and also of electroplated gold.

### **2.4 : PREGOS**

A single step, positive tone lift off process called Positive Tone REverse Gradient Of Solubility ( PREGOS) can be realized using the image - reversal type of photoresist, such as AZ 5200 series photoresist. The technique works using a UV

flood exposure applied to the film of resist that induces a positive solubility gradient through the film. A post exposure bake reverses this solubility gradient and the negative gradient is retained even after the image exposure, thus creating an overhanging resist profile which is suitable for metal lift off [Dunbobbin et al. 1988].

#### **2.4.1 : Processing**

After usual thorough cleaning of the surface of the sample, the adhesion promoter (primer) and the AZ 5200-series (AZ 5214 is used, which gives approximately 1.4  $\mu\text{m}$  of thickness) photoresist are spun on the sample at 4000 rpm for 30 seconds each. The sample is soft baked on a hot-plate in a convection oven at 90°C for 90 seconds. The sample is then flood exposed with a filter on (which provides a UV light with a wavelength of 200 nm and an intensity of 2.05 mW/cm<sup>2</sup>) in the HTG Mask Aligner for 2-3 seconds only. A post exposure reversal bake is performed after that on a hot-plate for 20 seconds at 110°C followed by image exposure for 22-23 seconds (at a wavelength of 450 nm with 2.05 mW/cm<sup>2</sup> intensity), the contact pressure between the substrate and the mask being 8 mm of mercury. The sample is then developed in the AZ 425 Developer for 40 seconds. The complete process sequence is shown in fig. 2.2. After the resist coating the initial flood exposure gives a positive solubility gradient which is reversed in the reversal bake. Metallization is done with negatively sloped resist layer to get a conductor thickness which is less than that of the resist layer. The metal scheme usually used was approximately 200Å of chrome followed by ~ 0.8  $\mu\text{m}$  of silver, both deposited with thermal evaporation. Metal lift off is then performed in acetone where the resist layer, with the metals on top of it, is removed leaving the metallized pattern of the CPW on the sample.

#### **2.4.2 : Discussion**

The yield of good negative gradient resist profiles was found to be very low. Analyses through SEM verified such failures, where it was detected that in

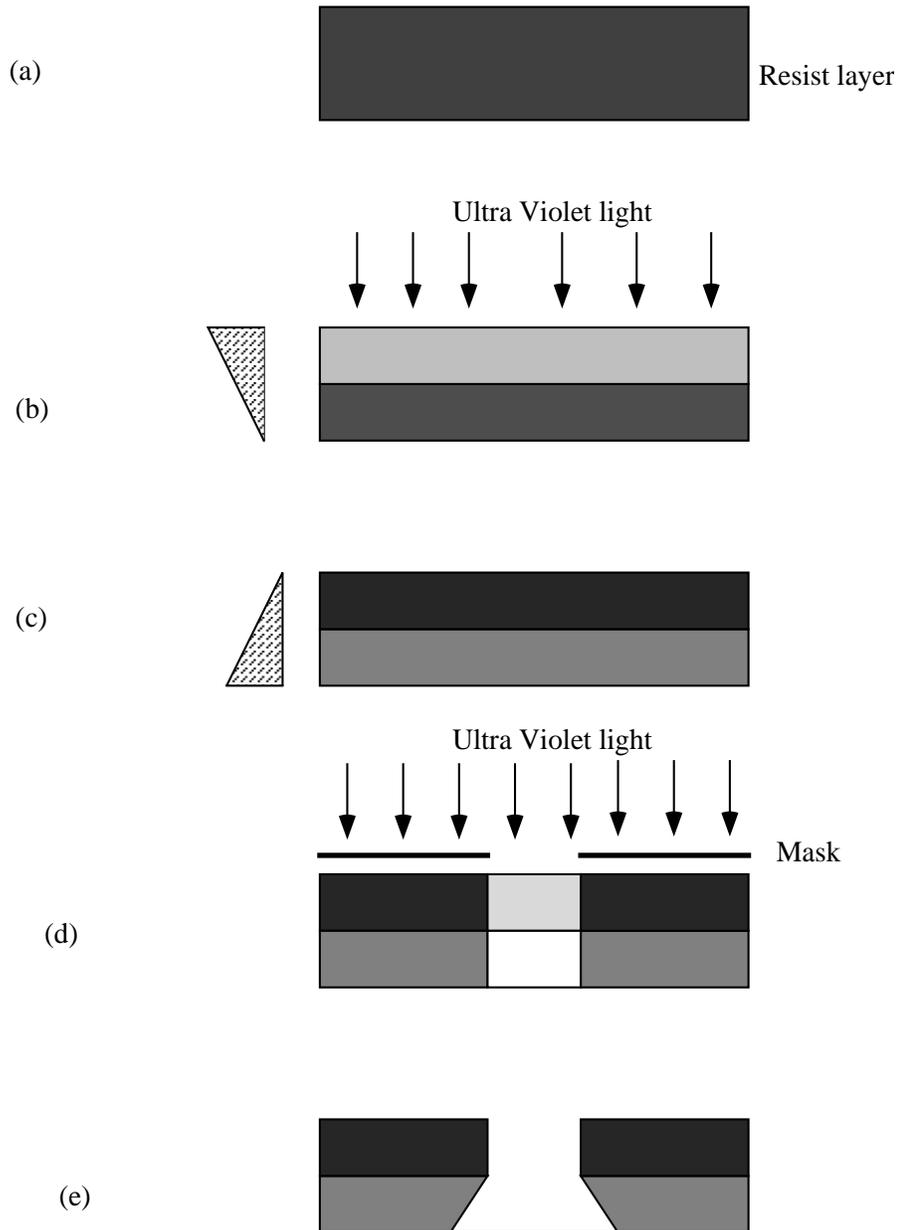


Fig. 2.2 : Process sequence of Positive Tone Reverse Gradient Metal Lift off technique. (a) Depositing resist layer, (b) Flood exposure causes positive slope of solubility gradient; (c) Baking reverses the solubility gradient (negative) such that solubility in the developer is higher in lower half of resist layer; (d) Imagewise UV exposure with mask; and (e) developer undercuts the bottom layer faster and thus creates an overhanging pattern.

most cases the resist profile was only straight at the most, instead of having a negative gradient. This whole process requires a very controlled environment in terms of cleanliness, humidity etc. [Dunbobbin et al. 1988]. Bad adhesion of 5200 series photoresist on GaAs substrates perhaps was another reason for such failures. Even after getting a moderate negative slope, metal lift off was not very successful, probably because of resist reflow due to the heat produced during the vacuum evaporation process.

## **2.5 : Polyimide metal lift off**

A very simple metal lift off technique was developed [Sadra 1993] by using a polyimide solution with no additional processing steps besides the spinning and baking of the polyimide. A very high yield was achieved with this method. One of the disadvantages of this technique is that the maximum thicknesses of the conductors are limited by the thicknesses of the polyimide layers. The polyimide used was EpoTek 600-3, which has a low solubility in aqueous type developer, like the one used for 5200-series or 1350J type photoresist development.

### **2.5.1 : Processing**

Processing starts with surface cleaning with acetone, ethanol, and DI water. The sample is immersed in HCl for 4-5 seconds to remove any native oxide layer and then rinsed in DI water thoroughly. The sample is then dry-baked at 125°C for 5 minutes and the polyimide solution is spun on for 30 seconds. Customized higher viscosity polyimide solutions (e.g., 20% EpoTek 600-3) were tried to get a thicker layer. However, the best results in terms of metal lift off were obtained with the original solution when spun on at a lower speed, like 2000 rpm and then curing it moderately hard. Curing of polyimide is accomplished by baking it at 125°C for 15 minutes in a conventional oven. It is to be noted that the surface of the sample has to be very clean and free of any native oxide layer before applying the polyimide, otherwise polyimide does not stick to the sample. Spinning of polyimide was tried on an SiO<sub>2</sub> surface but without any success in terms of adhesion. After baking of the polyimide, 5214-E photoresist is spun on the sample at 4000 rpm for 30 seconds. No adhesion promoter or primer is required because the photoresist itself

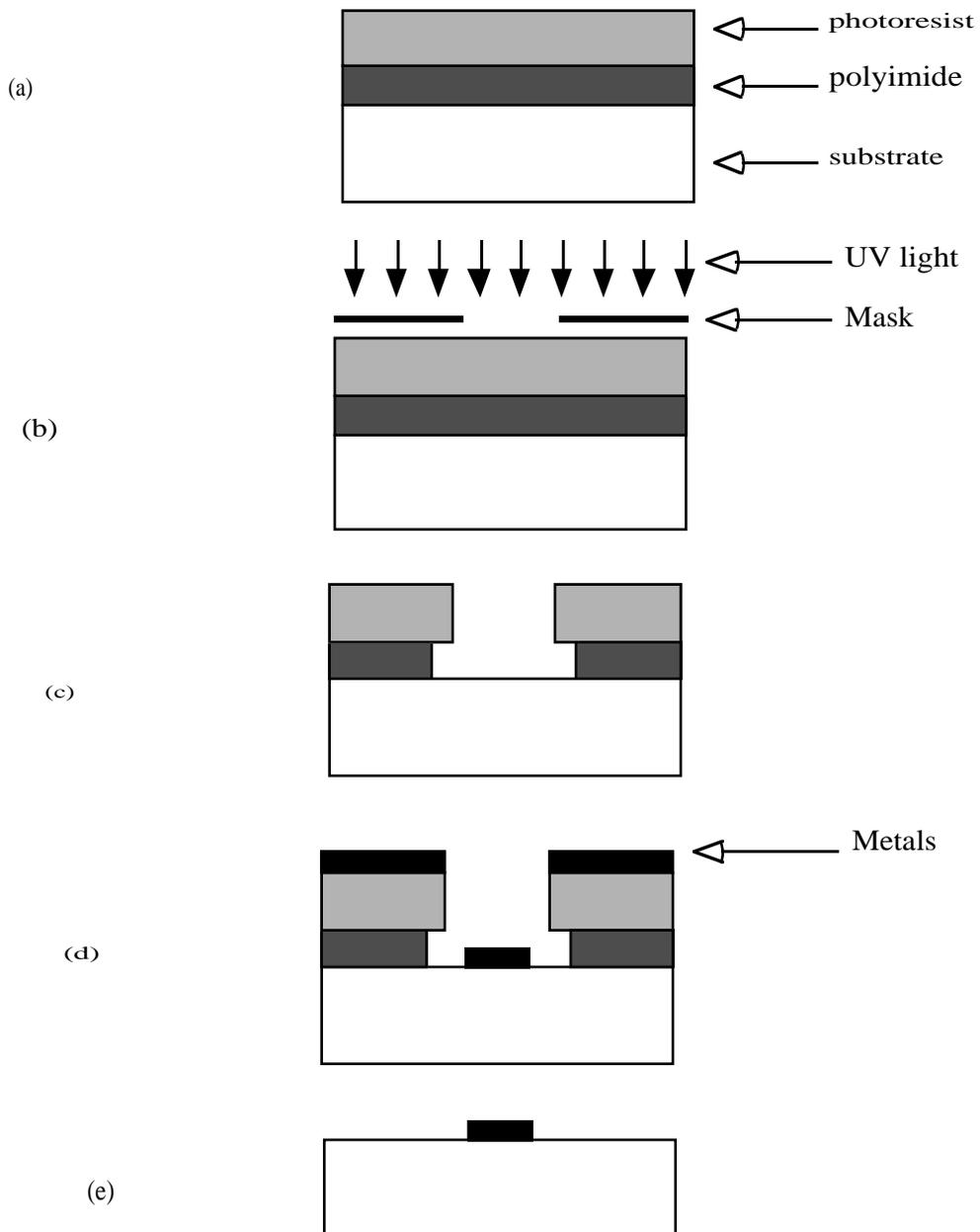


Fig. 2.3 : Process sequence of Polyimide Metal Lift off technique. (a) Depositing polyimide and resist layer, (b) Imagewise UV exposure; (c) Developing causes undercut in the polyimide layer; (d) Metallization; and (e) Metallized pattern after acetone removes resist-metal layers and developer dissolves the remaining polyimide.

sticks to cured polyimide very well. The sample is then prebaked on a hot plate in the oven for 90 seconds at 90°C. It is then imagewise exposed in the HTG Aligner for 21-22 seconds at 2.05 mW/cm<sup>2</sup> UV light intensity. Development of resist layer is very critical for this method. The developer (Developer AZ 425) not only removes the exposed region of photoresist but also slowly starts to etch the underlying polyimide as soon as all the exposed region resist is removed. The lateral undercut of polyimide in the developer solution is almost the same as its vertical etch depth. As a result, after the development, the resist layer forms an overhanging pattern. The development time is very critical in this case and it is observed that after the pattern becomes visible in the developer, it takes an additional 3-5 seconds for the optimum undercut in the polyimide. The sample is then checked under microscope with 100X objective and if properly developed, a small area of undercut can be distinguished by the difference of color. Approximately 1 micron of lateral undercut of polyimide is found to be the best, because a smaller one does not confirm a good lift off, whereas a larger one may even destroy the resist pattern. The complete process sequence of this positive tone metal lift off with image reversal photoresist is shown in fig. 2.3.

Metallization is done with the same metal scheme of 200 Å of chrome followed by 0.8 µm of silver, both deposited with thermal evaporation. Care is taken to evaporate this thick layer of silver so that the sample inside the vacuum chamber does not get overheated. Usually 0.8 µm of silver is evaporated in 3 to 4 steps, giving some cooling time in between the steps. After the metallization, the sample is immersed in acetone for metal lift off, where acetone dissolves photoresist and thus removes the metals on the top of that photoresist. Acetone etches the polyimide very slowly, as a result, only a small portion of polyimide is removed in acetone, leaving behind most of the polyimide. The sample is rinsed in AZ 425 developer and DI water for subsequent removal of all polyimide.

### **2.5.2 : Discussion**

The yield of processed devices with this polyimide method is 60-70%, which is better than that of any other processes mentioned above. Once a good undercut is found, a good metal lift off almost certainly follows it too. In a few cases lift off

flags were detected, but these did not pose a serious limitation for practical use of this method. This method is very simple and easy to use. Only special care is required while developing the photoresist layer for a nice and smooth undercut of the polyimide. As the undercut can be seen after the development, the metallization is done only if a good undercut is found, otherwise the resist and polyimide are removed and the sample can be used again. The criteria to choose the best type of polyimide solution include moderate thickness and slow etch rate in aqueous developer, which will ensure a thicker metal lift off and a controlled undercut in the developer. The maximum thicknesses of metals are dependent upon the thicknesses of the polyimide layer and the dimensions of the structures. The thickness of the polyimide layer and the smallest gap region in the mask need to be at least 120-150% and 300-400% higher respectively than that of maximum metallization.

## **2.6 : Epitaxial lift off**

The Epitaxial Lift Off (ELO) process is an excellent monolithic hybrid thin film integration technique [Yablanovitch et al. 1987] which permits a thin layer of epitaxially grown GaAs to be completely separated from its growth substrate and then bonded to any alternative surface. Here the CPW structure on GaAs epi-layer is lifted off from its semi-insulating substrate and put on a transparent quartz substrate, making backside illumination possible. Also it provides a background substrate of lower dielectric constant and of better insulating nature. Besides the use of a quartz substrate, a CPW on a thin film of GaAs has also been bonded onto an evaporated palladium layer to get a much lower sheet resistance underneath the GaAs film. The hybrid integration of epi GaAs CPW structure with quartz substrate resulted in better performance of the CPW in terms of insertion loss and degree of phase shift [Islam et al. 1992]. A brief discussion of the ELO method is given in the following and a detailed description is given elsewhere [Tsao 1993].

### **2.6.1 : Fundamental principle of ELO**

The Epitaxial Lift Off (ELO) technique was invented when Konagai and his co-workers investigated the "peeled film" technology for solar cells [Konagai et al. 1978] and later when Wu et al. examined the etch rates of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  in HF

solution [Wu et al. 1985]. Yablonovitch and his co-workers improved this technique and made this method a very practical alternative for hybrid integration [Yablanovitch et al. 1987]. This technique utilizes a thin layer of AIAs sandwiched between the epitaxially grown GaAs or  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  (with Al mole fraction,  $x$ , being less than 0.4) and the growth substrate of GaAs. The AIAs layer has an etch rate several orders of magnitude higher (approximately  $10^7 - 10^8$ ) in 10% HF solution than that of GaAs or  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $x < 0.4$ ). Due to this high etch selectivity, 10% HF solution etches the sandwiched AIAs layer much faster than the epi-layer or the growth substrate. And this undercut ensures the complete separation of the epi-layers from their growth substrates. Black wax is used as a carrier for the separated epi-film to facilitate the manipulations and bonding of the thin epi-layer to an alternative substrate.

### **2.6.2 : Processing of ELO**

ELO is performed after the CPW is fabricated and tested, so that comparison can be made between the results both before and after ELO process. As a first step, the Apiezon W wax (black) is applied onto the already processed devices. This wax is resistant to acids, such as HF, HCl and  $\text{HNO}_3$ , and dissolves in TCA or TCE. Usually the wax is melted directly onto the sample and pressed gently with a teflon-coated tweezer. After the application of black wax, the exposure of AIAs layer at all side edges are checked. In some cases the black wax is annealed to get a good dome-like shape on the top of the ELO sample. Once the black wax is properly placed on the sample, the sample is dipped into the 10% HF solution kept at  $0^\circ\text{C}$ . This low temperature is to prevent excessive  $\text{H}_2$  bubble formation, which can impede the complete undercut of the AIAs layer. The time required for complete undercut of the AIAs layer depends on the size of the sample and usually requires several hours. As the 10% HF etches the AIAs exposed at the side edges of the sample, the tension in the black wax causes the film to peel upward at the edges, as shown in fig. 2.4. After complete etching of the AIAs, the wax and the thin film separate from the substrate, slide away from the substrate and either float to the top of HF solution or remain underneath the etch solution. With the ELO film suspended in the etch bath, the HF solution is diluted completely with water and a pen vacuum probe is used to

manipulate the film without any damage or crack. The pen vacuum probe is tied to a water trap, so that ELO film can be manipulated completely under water, which is essential for cleanliness of the process. The sample is placed onto the alternative substrate with the help of the pen vacuum probe and bonded to the substrate either using Vander Waal's force or using some kind of adhesive materials, such as cyanoacrylate (commercially known as super glue). Vander Waal's force bonding requires absolute cleanliness of the process which is realized by manipulating and bonding the film onto the substrate, all in a DI water environment. Once the film is placed onto the substrate, pressure is applied with the help of a vacuum bag to which a vacuum line is tied to a water trap [Tsao 1993]. Vacuum is used to draw all water out of the bag and as the water is removed, the sample and substrate are pressed together with the uniform pressure on the top of black wax. A lint-free kim-wipe is used in between the vacuum bag and the black wax to apply an even and uniform pressure. The vacuum bag assembly with the ELO film-substrate combination is sometimes placed in an oven at 40°C-50°C to remove any remaining moisture from the substrate and ELO film. As an alternative of Vander Waal's force, adhesive

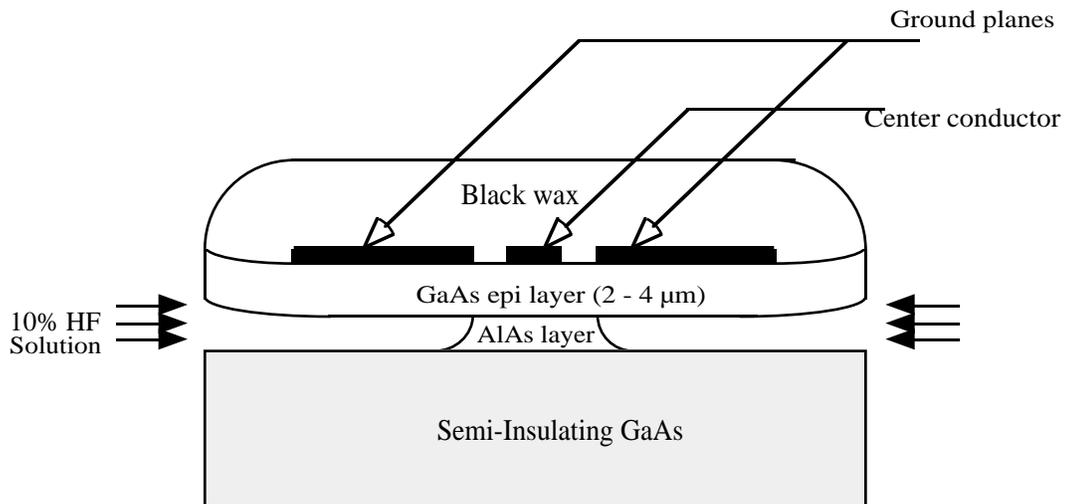


Fig. 2.4 : Epitaxial Lift Off (ELO) process, where AlAs layer is being undercut by 10% HF solution while black wax is acting as a mechanical support for the thin film and CPW conductors. After [Tsao 1993].

materials or a metal base can also be used. As an adhesive material, cyanoacrylate is an excellent choice, which is optically transparent, electrically insulating and possesses good adhesion between the semiconductor film and an insulating substrate such as quartz. Vander Waal's force cannot be used with a metal substrate because of charge screening. With a metal substrate, a conductive adhesive such as silver epoxy or polyimide has been tried with some limited success, mainly because the size of the silver flakes, dispersed in the epoxies, are on the order of the ELO film thicknesses and thus provide poor mechanical contact to the substrate [Tsao 1993]. Metal / alloy bonding is a promising choice for epitaxial lift off on an evaporated metal substrate. Bonding on substrates coated with palladium (Pd) is an excellent choice, because Pd displaces any native oxides and reacts with the GaAs. Palladium based contacts to GaAs provide smooth and uniform surfaces, and as a result an excellent bond and a good electrical contact.

### **2.6.3 : Discussion**

Epitaxial lift off provides an excellent and simple way for hybrid integration of semiconductor CPW and a completely insulating material like quartz or a metal substrate like palladium. Use of quartz allows backside illumination and thus avoids any metal shadowing effect. Use of palladium provides a choice for a low back side sheet resistance and hence lower series resistance at the back. Epitaxially lifted off CPW on quartz and a lifted off LED or laser on the back side of the same quartz substrate could provide the opportunity of implementing an integrated optically-controlled CPW phase shifter.

The epitaxial lift off technique can also be applied to other microwave devices, such as double barrier resonant tunneling diodes (DBRTDs) [Tsao et al. 1992], quantum well injection transit time diodes (QWITTs) [Tsao et al. 1991], GaAs Schottky photodiodes [Kobayashi et al. 1992] etc. In most cases use of ELO

with these devices shows improvement in their performance by providing better heat sinking or better electrical or optical contacts.

## **2.7. : Summary**

In this chapter, a detailed discussion on device (CPW) fabrication has been presented. The processing steps to fabricate a long transmission line with narrow linewidth and a narrow gap region associated with thick metal electrodes were critical. Careful studies and observation were required for the successful fabrication of the CPWs. In addition to simple fabrication, a more advanced processing technology (Epitaxial LiftOff) was used to peel off the thin epitaxial layer of GaAs from its parent SI GaAs substrate and to place it onto an alternative substrate.