

UNIVERSITY OF OSLO

FACULTY OF MATHEMATICS AND NATURAL SCIENCES

Guide for this exam shown with yellow background:

Exam in: FYS4260 Microsystems and Electronic Packaging & Interconnection Technologies

Day of exam: Monday, May 30th, 2011

Exam hours: 09:00 – 12:00 (3 hours)

This examination paper consists of 4 page(s).

Appendices: No appendices

Permitted materials: None except the general allowed aids as for instance approved electronic calculators. For instance, tables and programmed data in calculators not allowed.

Make sure that your copy of this examination paper

is complete before answering.

Additional information:

Course responsible Per Øhlckers might not be present at University of Oslo on exam day but can be reached on cell phone 9590 3989. / Kursansvarlig Per Øhlckers vil kanskje ikke være tilstede på Universitetet i Oslo på eksamensdagen men kan nåes på mobiltelefon 9590 3989.

The test questions are given in Norwegian and English, and can be answered in either Norwegian or English. Use maximum 1 page for each question; that is for the sum of both the a) and the b) answers. Each question is equally weighed when grading the answers / Hvert spørsmål gis både med norsk og engelsk tekst. Besvarelsen kan gis valgfritt på norsk eller engelsk. Bruk maksimum 1 side på hver oppgave, dvs. summert for både a) og b) besvarelsen. Hvert spørsmål vektet likt ved bedømming av svarene.

Question 1: Technology trends

Background information: From Statistics Norway:

http://www.ssb.no/english/subjects/10/12/20/vtbaar_en

Lowest number killed in road traffic since 1954

A total of 212 persons were killed in road traffic accidents in 2009; 43 fewer than the year before. The number of injuries dropped significantly from 2008 to 2009.

A total of 9 844 persons were injured in road traffic accidents last year; about 1 000 fewer than in 2008. The average over the period 2000 to 2009 was 263 fatalities and 11 469 injuries per year. Despite the variation in fatality and injury figures from one year to the next, there is a downward trend over the 10-year period.



Figure 1.a: Road traffic accidents from year 2000 to year 2009.

- a. As seen from the graph and text above, road traffic fatalities in Norway have been dropping steadily for many years. Assumedly, there are many reasons for this positive trend, for instance better drivers and roads. However, it is obvious that wider use of electronics and microsystems used in automotive safety systems has contributed heavily to this trend. Describe the most important microsystem-based safety systems in automotive vehicles today, and describe how they work to reduce road traffic fatalities.

Suggested answer:

The most important microsystem based safety systems in automotives today are:

- I. *Crash sensors for airbag systems being deployed at occurrence of dangerous accidents like crashing with other cars or objects, or running out of the road. The most used sensors are accelerometers (front crash), pressure sensors (side crash) and gyroscopes (rotation into the ditch).*

- II. Tire pressure measurement systems with pressure sensors warning about faulty pressure.
- III. Steering assistance sensors like anti-skid.
- IV. Antilock brake systems (ABS)
- V. Temperature sensors for icy road warning.
- VI. Radar systems for anti-collision control

b. However, it is often commented that automotive electronics and microsystems in general are unreliable. Comment why this perception – true or untrue – is widely accepted, and put up a list of at least 4 examples of reliability problems and their most likely causes.

Suggested answer:

Some main factors for the reliability problems associated with automotive electronics and automotive microsystems most important microsystem based safety systems in automotives today are:

- I. Electronics and sensor are operating in very harsh environment, like high temperature differences, vibration, aggressive gases, etc.
- II. A lot new electronics and microsystems have been added to cars the last 10 to 15 years making the car just as much an electronic system as a mechanical, and such technology shifts tends to have a lot of infancy problems that gradually are improved as field experiences are gained.
- III. Simply the increased complexity means that there are more components that can fail.

Examples can favourably be given, for instance the Toyota Prius incidents, with the accelerator pedal locking into full speed, panicking the driver.

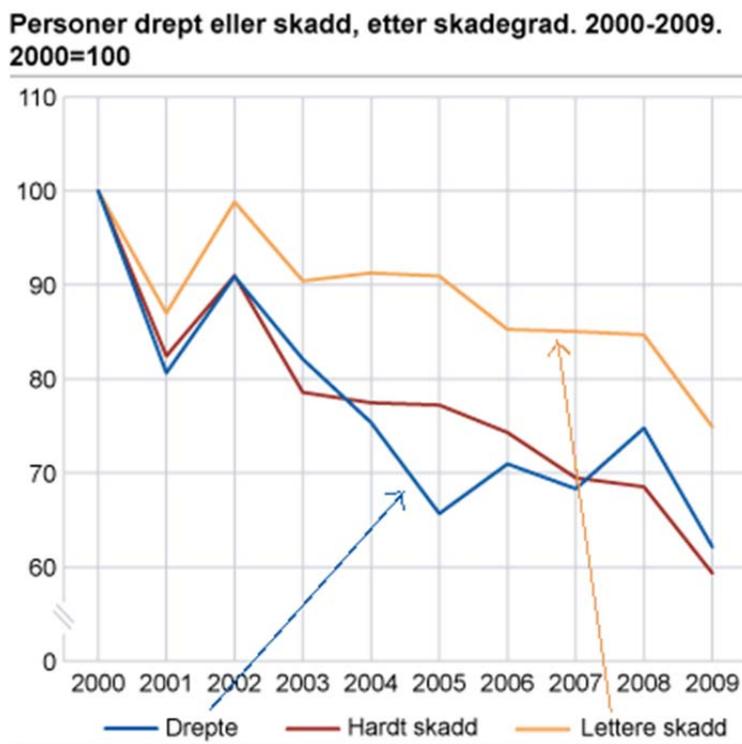
Oppgave 1: Teknologitrender.

Bakgrunnsinformasjon: Fra Statistisk sentralbyrå: <http://www.ssb.no/vtuaar>: Veitrafikkulykker med personskade, endelige tall 2009:

Laveste antall omkomne på over 50 år

212 personer omkom i veitrafikkulykker i 2009. Dette er det laveste antallet siden 1954. For første gang siden 1966 ble færre enn 10 000 personer skadd i trafikken.

I 2009 ble det i alt registrert 186 dødsulykker med totalt 212 omkomne, ifølge statistikken over politirapporterte veitrafikkulykker. Dette er 51 færre dødsulykker og 43 færre omkomne enn året før. Selv om ulykkesstallene varierer mye fra et år til et annet, viser den langsiktige trenden en betydelig reduksjon, særlig for de alvorlige ulykkene. Gjennomsnittet for 10-årsperioden 2000-2009 var 235 dødsulykker og 263 omkomne per år.



Figur 1.a: Veitrafikk dødsfall fra år 2000 til år 2009.

- Som beskrevet i ovenstående figur og tekst, har trafikkdødsfall i Norge falt jevnlig over mange år. Antageligvis er det mange grunner til denne positive trenden, som f.eks. bedre sjåførere og veier. Dog er det opplagt at mer utbredt bruk av elektronikk og mikrosystemer i automotive sikkerhetssystemer har bidratt vesentlig til denne trenden. Beskriv de viktigste mikrosystembaserte sikkerhetssystemer i bilkjøretøyer i dag, og beskriv deres virkemåter for å redusere veitrafikk dødsfall.
- Dog, det kommenteres ofte at automotive elektronikk og mikrosystemer generelt er upålitelige. Kommenter hvorfor denne oppfatningen – sann eller usann – er bredt akseptert, og sett opp en liste med minst 4 eksempler av pålitelighetsproblemer og deres mest sannsynlige årsaker.

Question 2: Components: Plastic or ceramic packages

- List the most important advantages and disadvantages of respectively plastic IC packages and ceramic IC packages, and give for each type two examples of typical applications.

Suggested answer:

See page 4.15 – 16:

Plastic:

- Not hermetic.
- Low price in large component quantities.
- High initial cost for tooling etc., not suitable for prototypes of custom circuits.
- Poor thermal conductivity of the plastic ($0.2 \text{ W}/^\circ\text{C}\cdot\text{m}$, somewhat higher with special additives).
- Tolerate only limited time at high temperature (SMD soldering processes).
- High thermal expansion coefficient ($25 - 50 \text{ ppm}/^\circ\text{C}$) and thermal mismatch to Si chip and to metals. This is important for large Si chips and large packages.

- g. -High demands on plastic quality and moulding process. If not satisfied, the long-term reliability will suffer.
- h. -Not suitable for high frequency circuits which require controlled characteristic impedance.
- i. -Special failure mechanisms (please refer to Section 3.3 and Chapter 9).

Example 1: PC Motherboard – mostly used in benign environment, and low cost is important.

Example 2: Consumer electronics like an electric toy car – cost, cost and cost are the main issues.

Ceramic:

- a. -Hermetic, give good reliability.
- b. -Costly, even in large volume, but Si chips can easily be mounted into pre-made packages, important for prototyping.
- c. -Good thermal conductivity (15 - 30 W/°C·m for alumina).
- d. -Low thermal coefficient of expansion (5 - 7 ppm/°C for alumina), gives thermal mismatch to organic substrates. This can be serious for leadless packages.
- e. -Leadless packages have gold metallisation, which must be removed before soldering (see Section 4.7).
- f. -Can be manufactured with well-defined high frequency properties.

Example 1: Defence electronics – risk of harsh environment, and reliability much more important than cost..

Example 2: Telecommunication systems such as a satellite telephone: High frequency properties are important.

Plastic packages dominate for ordinary uses. Ceramic is used for critical military and telecommunication systems, where hermeticity is required to get supreme long term reliability. They are also used for electrically and thermally demanding systems, see later (and in Chapter 6).

During the last years the reliability of good plastic packaging has improved much and is used increasingly even in the most demanding telecom- and military equipment.

- b) Describe a Pin Grid package, and explain why Pin Grid packages usually are socket mounted.

Suggested answer:

See page 4.18:

The Pin Grid Package

Large VLSI circuits often have more than the maximum 64 I/Os available as a DIP. The largest hole mounted IC package is the pin grid, with leads on a grid of 100 mils lead separation, please refer to Figure 4.18. The pin grid is most frequently made of alumina ceramic, with up to 400 - 500 leads. There may be up to 6 - 10 layers of ceramic. Pin grid packages are made "cavity down" or "cavity up", depending on whether the heat should be removed down into the substrate or up, into a cooling fin (see Chapter 6). They use the board area better than the DIP and have very good thermal performance, but they are expensive. Once they are soldered onto the board, it is difficult to de-solder and remove them (repair). Therefore, they are often mounted in a socket. Routing the wiring to a pin grid package normally requires more than two layer boards.

Some standard products are supplied in plastic pin grid packages.

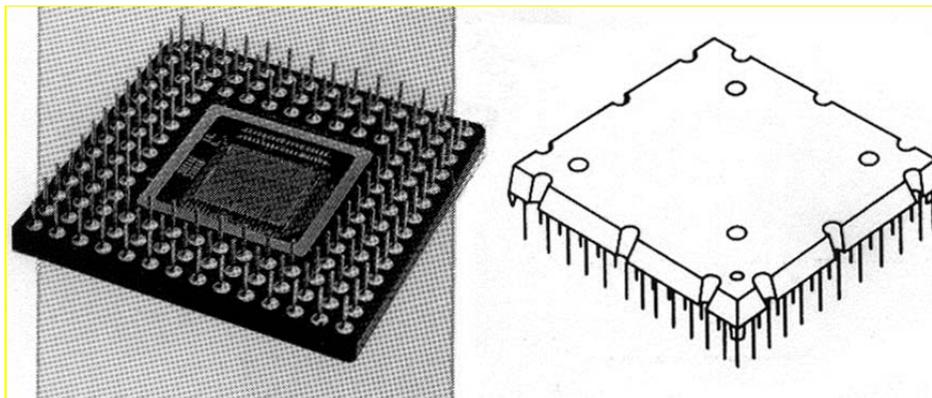


Fig. 4.18: Pin grid packages: To the left a cavity up ceramic package, and to the right a plastic moulded package.

Oppgave 2: Komponenter: Plastkapsler eller keramiske kapsler.

- a) List opp de viktigste fordeler og ulemper ved henholdsvis plastkapsler og keramiske kapsler for integrerte kretser, og gi for hver type to eksempler på typiske bruksområder.
- b) Beskriv hvordan en Pin Grid kapsel er utformet, og forklar hvorfor Pin Grid kapsler som regel blir sokkel-montert.

Question 3: Printed wiring boards (Unassembled printed circuit boards)

- a) Describe a common used manufacturing technology for a 4 layer through hole plated double sided printed wiring boards. This is best done by outlining a flow chart with a supplemental text for each process step.

Suggested answer:

See page fig 5.7, page 5.14 and page 5.12-13:

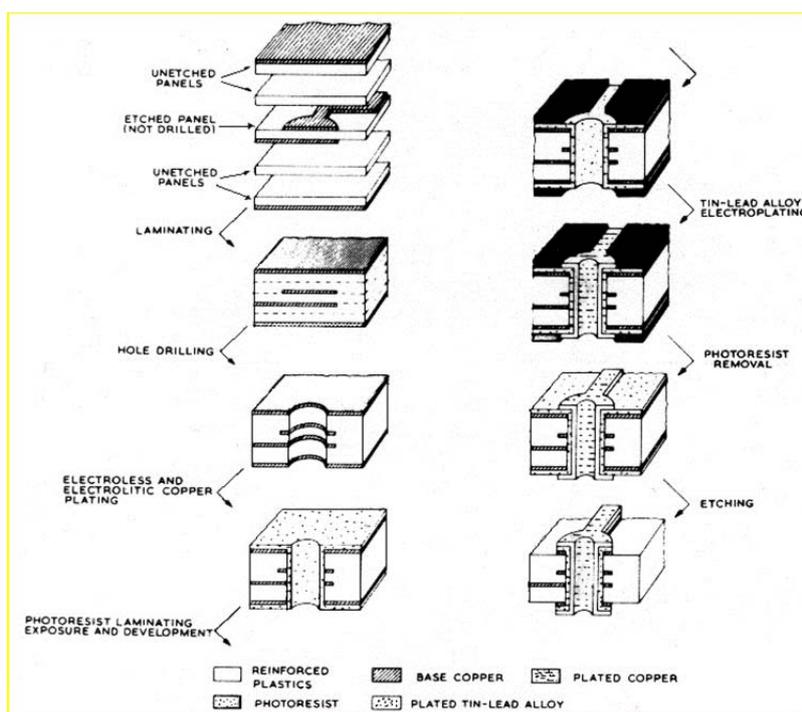


Fig. 5.7: Process steps for multilayer printed wiring boards with holes only through the board.

The most common types of multilayer boards only have via holes that run all the way through the whole laminate. For a 4-layer board the process is as shown in Figure 5.7:

1. Drilling of registration holes in all layers. Chemical/mechanical rinse.
2. Conductor patterns on the panels with inner layers are defined by photo processing.
3. Conductor patterns on the inner layers are etched, and the panels are rinsed.
4. "Black" or "brown"-oxidation of the Cu-surfaces: These are special oxidation processes in high temperature, which have the purpose of giving a rough surface and improving the adhesion in the lamination process following later.
5. Baking: Heating of the panels to evaporate water and solvents.
6. Lamination: The panels are placed on top of each other with accurate registration by guiding pins in the registration holes, with a single sided panel for outer layer on top and at the bottom, and prepreg between each panel. The stack is pressed together in a lamination press typically at 10 - 25 atmospheres of pressure at 170 °C, for 30 - 90 min. In this process the epoxy softens in the prepreg material, fills all non-uniformities, and polymerises completely to the C-stage.
7. Drilling of via holes through the board for subsequent through hole plating. The drilling process is more critical than for double sided boards, because here we must have electrical contact between the hole plating and the inner layer conductor layers at certain places. Often the epoxy softens and creates an insulating layer on the walls of the holes ("smearing"). To remove this layer, an etch process is used, often plasma etching ("de-smear").

The subsequent processing for pattern definition on the outer layers, through hole plating, etc., is similar to that for double layer through hole plated boards

- b) Explain the other two most important functions for a printed wiring board, in addition to its function as electrical interconnection. Explain shortly the most important design difference when a 4-layer through hole plated board is used for hole-mount technology and surface mount technology, respectively.

Suggested answer:

See page 5.1:

The substrate on which the components are mounted has several purposes: In addition to giving electrical interconnection, "wiring", between components and other parts of the system, the printed wiring board has 2 main functions:

- I. Mechanical support for the components.
- II. Conduction of the heat from the components.

See page 6.7-8:

SMD components that are wave soldered have a preferred orientation with respect to the solder wave, see Figure 6.6. Solder bridges, non-wetted areas and the effect of "shadowing" are reduced in this way (see Section 7.3). The shadowing effect is more pronounced for tall packages. There should be a minimum distance between components. The reasons are:

- Reducing solder bridging
- Take care of tolerances in component size
- Necessary space for the mounting head of the pick and place equipment
- Tolerances in the placement accuracy
- Ease of repair, visual inspection, space for de-soldering equipment, etc.

Oppgave 3: Mønsterkort (Ubestykkete kretskort)

- a) Beskriv en vanlig benyttet fremstillingsmåte for et 4-lags gjennomplettet mønsterkort. Dette gjøres best ved å skissere et flytdiagram og med en utfyllende tekstforklaring for hvert prosessstrinn.
- b) Forklar de to andre viktigste funksjonene til et mønsterkort i tillegg til å skape elektrisk forbindelse. Forklar kort den viktigste konstruksjonsforskjellen dersom et 4-lags gjennomplettet mønsterkort skulle vært brukt for henholdsvis hullmontasjeteknologi og overflatemontasjeteknologi.

Question 4: Thin film technology

- a) Explain a widespread way of making thin film hybrid circuits. This is best done by sketching a flow chart with a complementary text explanation for each process step.

Suggested answer:

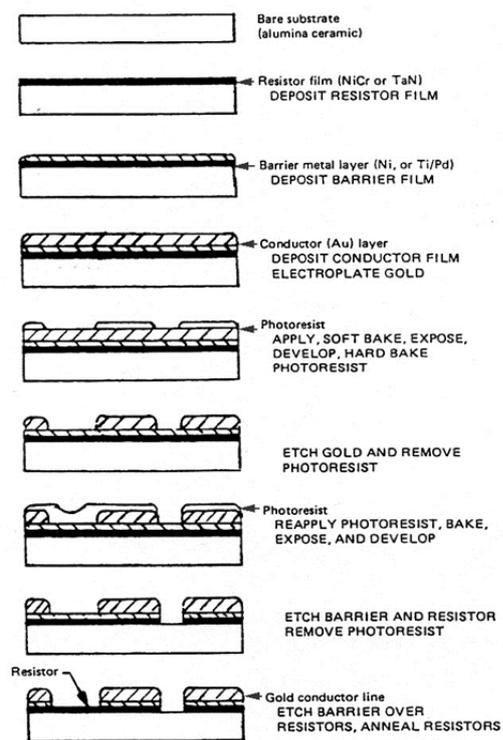
See Chapter 8.4, page 8.18-27:

Thin film circuits consist of conductor layers, resistor layers and dielectric layers, similarly to thick film circuits. However, the thin film thicknesses are normally 1 μm or less, an order of magnitude less than for thick film. Processes from silicon technology are used for deposition and definition of patterns. That gives higher circuit density than in thick film. The materials are also generally different. In this section, we shall concentrate on the form of thin film hybrid technology that has been in use since the 1960's, with one layer of conductor, one layer of resistor and an inorganic dielectric.

The substrate materials that are used the most, are glass and 99.6 % alumina. The fine conductor dimensions in thin film require a smoother and more uniform surface underneath, so the substrates are polished. For high frequency use, low losses are important and the purer quality alumina, used in thin film circuits, has lower $\tan \delta$ than the substrates used in thick film technology, Table 8.1.

The metals that are used the most for thin film conductors are gold and aluminium. Gold is chemically stable, it has high electrical conductivity and good bondability. However, as previously mentioned, gold diffuses very fast into many other conductor and insulating materials. Together with gold special elements are used as diffusion barriers, and in addition as adhesion layers, because gold has poor adhesion to many materials. Nickel is suitable for diffusion barrier, a nickel/chromium alloy improves the adhesion, and it is also suitable as resistor material, see below. The much used Au - NiCr system is deposited by vacuum evaporation or by sputtering, please refer to Chapter 3. Gold may also be electrolytically plated, particularly for microwave circuits, where a 5 - 10 μm thick layer gives low conductor resistance, which is important to achieve low high frequency loss. (Please refer to Section 6.7).

Production process: See following figure:



The thin films of conductors, resistors and dielectrics are deposited by vacuum evaporation or sputtering. The dielectric can sometimes be a polymer like polyimide which most often is deposited by spinning and drying. The vacuum evaporation and sputtering deposition equipments are shown in the following figures.

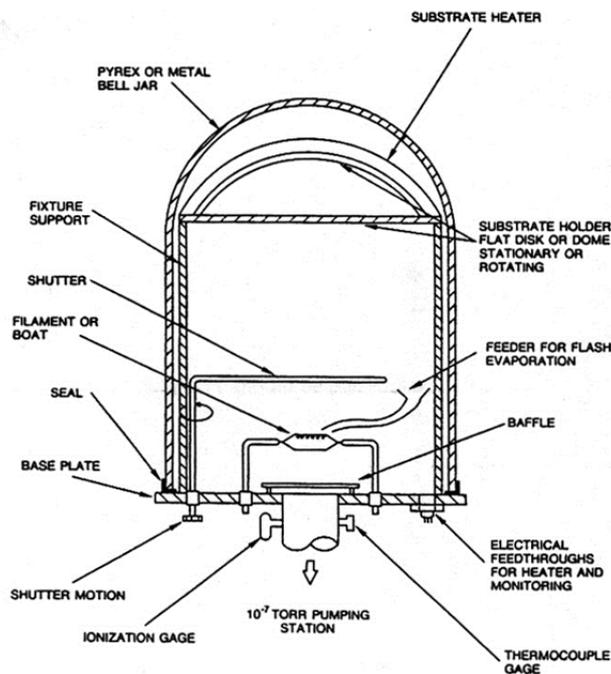


Fig. 3.12: Vacuum evaporation.

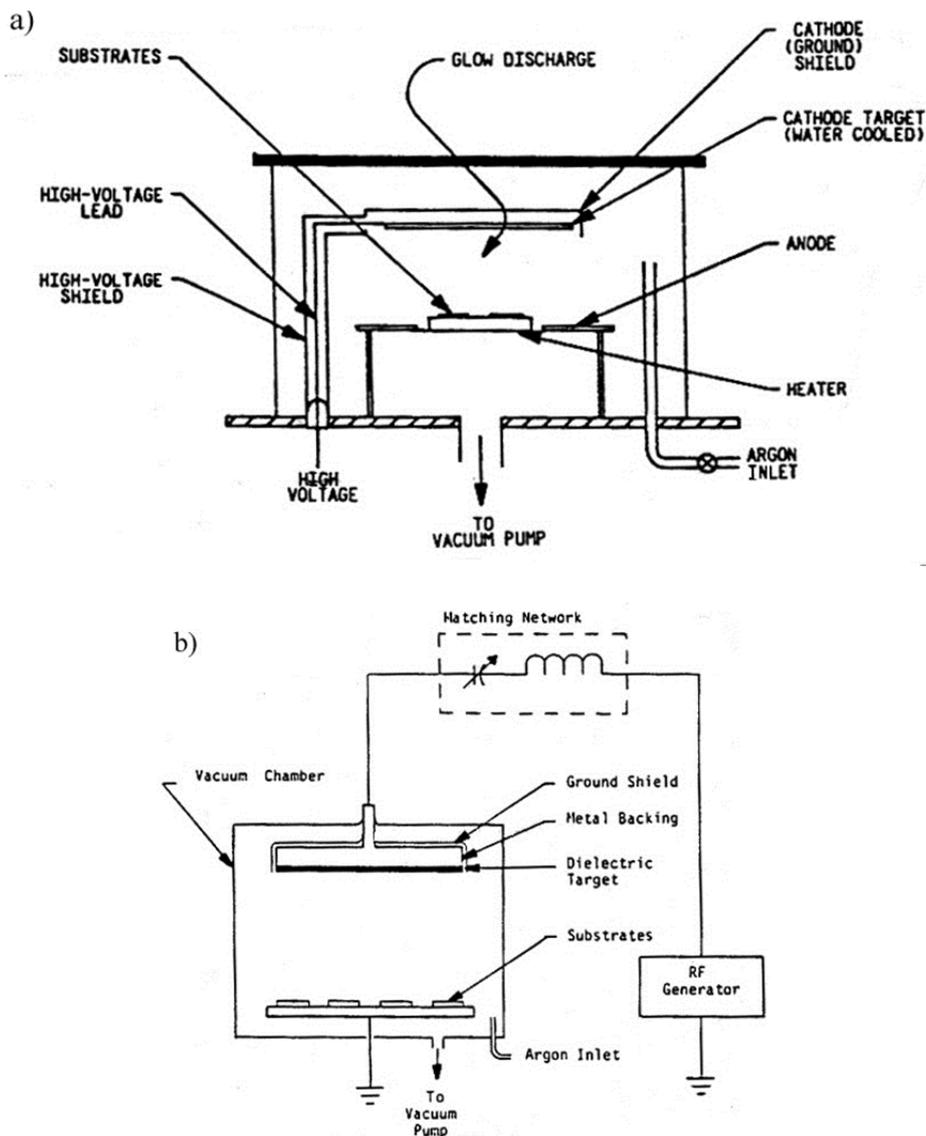


Fig. 3.13: Sputtering: a): DC sputtering, b): Radio frequency AC sputtering [3.8].

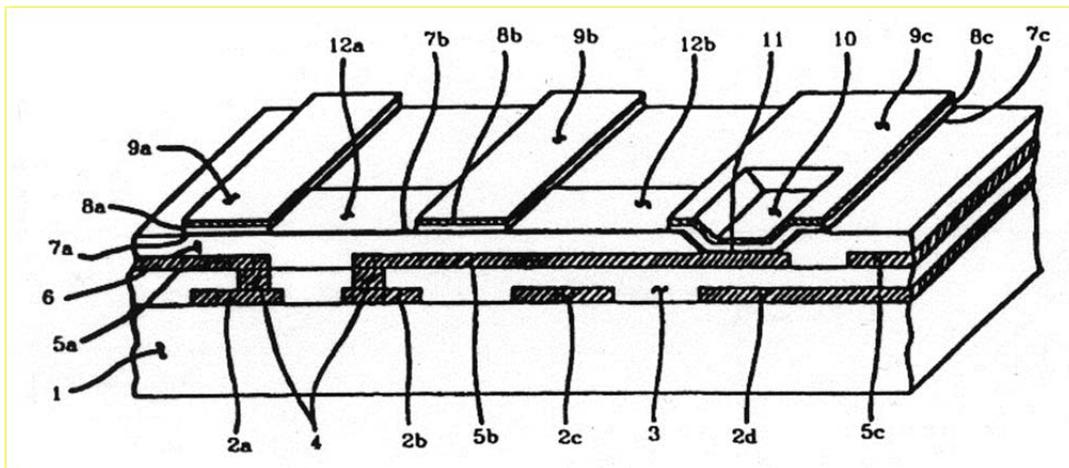
- b) Propose a technical and cost wise a good way to combine thin film technology and high temperature thick film technology in the same hybrid circuit. Point out advantages and disadvantages by such combifilm technology, and give 2 possible application examples.

Suggested answer:

See Chapter 8.72, page 8.38-39

Thin film on thick film

AME in Horten, Norway, has developed a combination of regular thick film and regular thin film technology, see Figure 8.25. All slow and non-critical signals, in addition to ground and power planes, are made in thick film. On top are a ground plane, printed dielectric and one layer of thin film conductors for high speed signals with transmission line dimensions.



- 1 Alumina substrate.
- 2 a,b,c,d: Printed conductor on first layer.
- 3 Printed dielectric film.
- 4 Optional compensation printed in vias.
- 5 a,b,c: Printed conductor on second layer.
- 6 Glass based dielectric.
- 7 a,b,c,d: Tantalum nitride resistive layer.
- 8 a,b,c,d: Molybdenum diffusion barrier.
- 9 a,b,c: Thin film gold lines.
- 10 Via hole between thin film and thick film conductive layer.
- 11 Contact area in thick film. Gold-platinum or gold-palladium.
- 12 a,b: Resistor in thin film made by selective etching in thin film structure.

Fig. 8.25 AME's combination technology combining thick film and thin film, cross section [8.25].

Oppgave 4: Tynnfilmteknologi

- a) Forklar en vanlig benyttet fremstillingsmåte for multilags tynnfilmkretser med tynnfilmotstander. Dette gjøres best ved å skissere et flytdiagram og med en utfyllende tekstforklaring for hvert prosessstrinn.
- b) Foreslå en teknisk-økonomisk god måte å kombinere tynnfilmteknologi og høytemperatur tykkfilmteknologi i samme hybridkrets. Påpek fortrinn og ulemper ved en slik kombifilmteknologi, og gi 2 mulige anvendelseksempeler.

Question 5: Micromachined devices

- a) Give a list of 5 important process technologies which can be used for micromachined devices with a short explanation on how they work.

Suggested answer:

See Chapters 9.3-6, pages 9.19-27.

As an example, we take:

Bulk micromachining

Bulk micromachining can be defined as three-dimensional micromachining in a bulk material by means of photolithographic etching techniques. This definition covers most bulk techniques used to make micromachined devices, although in some cases mechanical drilling or other machining methods are used. Bulk micromachining in single crystal silicon based on wet chemical etching is the dominating technique, and the way it is done illustrates the concept of in a very informative way. The most popular materials for bulk micromachining in addition to single crystal silicon are glass, quartz and gallium arsenide.

The etching techniques used in bulk micromachining of silicon are most often wet chemical etching, some isotropic and some anisotropic attacking the different crystal direction with different speed. By impurity doping selective etching can be obtained with etching speed dependent upon doping configuration. The anisotropic etching technique is the dominating, as this method, especially when combined with selective etching behaviour, gives the highest dimensional accuracy and repeatability with an accuracy down towards 1 μ meter. High accuracy is crucial as this opens up for miniaturisation giving performance and cost improvements for products based on this technology.

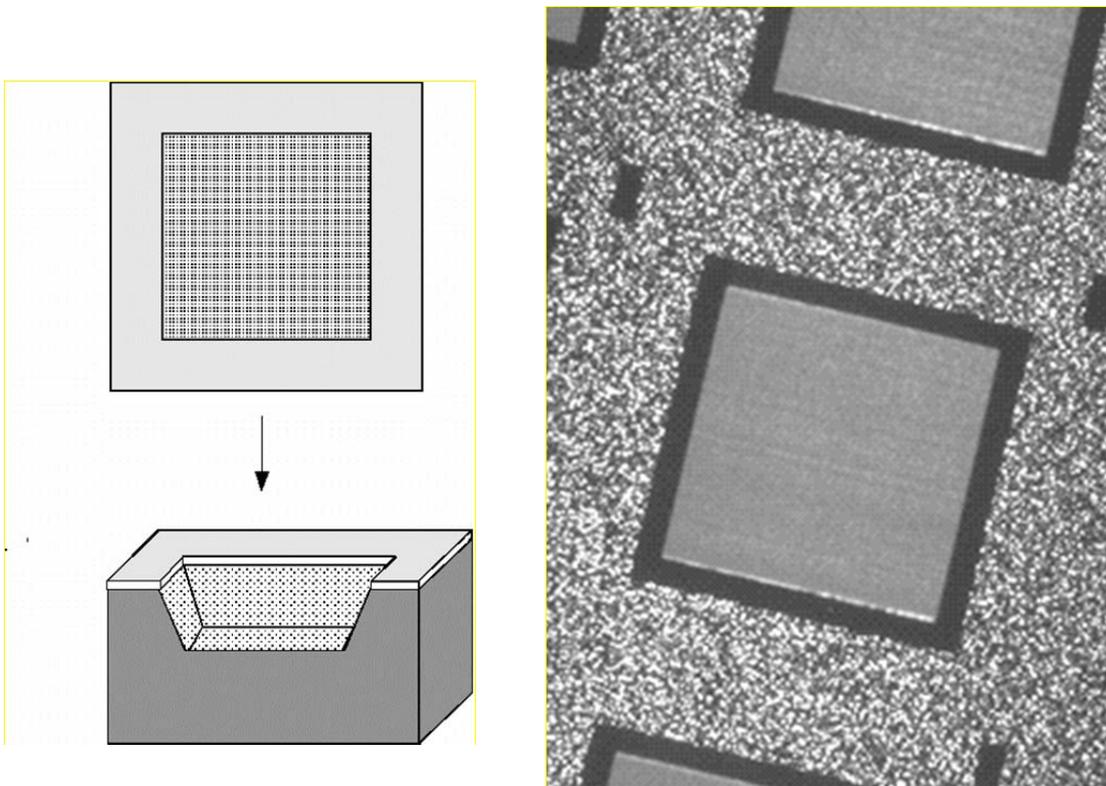


Fig. 9.9: Anisotropic etch cavity in (100) silicon with a square masking film opening oriented in parallel with the direction. Due to the four-fold symmetry of the slow-etching (111) planes, sideways etching is stopped giving a cavity with four sloped side walls. The photography shows such an etched cavity.

The other 4 technologies could be:

II: Double-sided photolithography

Many micromachined devices need precisely aligned double-sided patterning during the production process, e.g., silicon piezoresistive micromachined pressure sensors have their resistor network processed on one side of the wafer and the micromachined diaphragm processed from the other side. This calls for methods for precise double sided alignment. Mechanical alignment systems

ensuring correct x-y positioning by using the circumference of the substrate or wafer as reference is one way to do it, but infrared see-through-wafer aligners are most popular. These aligner are mostly standard aligners with an infrared camera as add-on equipment. At SINTEF we have a Karl Süss MA56 aligner with infrared camera as add-on equipment, and we achieve a side-to-side alignment precision within a few microns.

III. Anodic wafer bonding

Anodic wafer bonding is based upon the anodic bonding sealing process that can be defined as a method of electrostatically bonding two dissimilar materials together to form a strong, hermetic seal that involves little alteration in the shape, size, and dimensions of the members making up the joint. It is a high yield wafer-to-wafer sealing method that makes it possible to obtain hermetic seals. The technique was first developed for silicon-to-glass anodic wafer bonding, and has later been further developed to silicon-to-silicon anodic wafer bonding and silicon-to-thin film anodic wafer bonding.

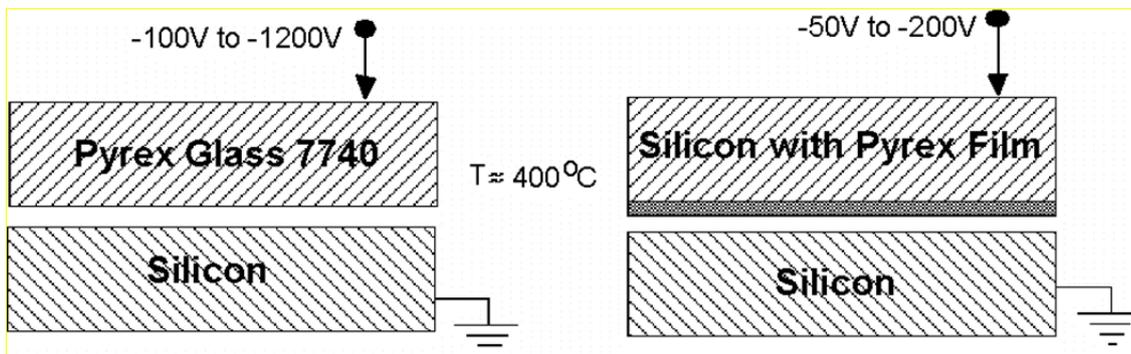


Fig. 9.10: Schematic view of silicon-to-silicon anodic bonding and silicon-to-glass anodic bonding.

IV. Epitaxy

Epitaxy is used to grow a single crystal (semiconductor) layer of controlled thickness, composition and doping on top of a single crystal (semiconductor) substrate in such a way that the crystal structure of the substrate is extended unperturbed into the epitaxial layer.

V. Diffusion of dopants

The thermal diffusion technique as a way of introducing electrical active impurities in a controlled way into silicon is the most important way to alter the electrical characteristics of silicon and other semiconductors. Impurity levels in the range of one/tenth of a percentage and down to parts per million are used to alter the resistivity and type of main conduction mechanism (p-type or n-type) giving the possibility to make resistors, transistors, etc.

Diffusion of impurities takes place in diffusion ovens, operating in the range from approximately 800°C to 1200 °C with tight temperature regulation and gas as impurity source.

- b) Propose a list with 10 important success factors stimulating the application of micromachined devices, and for each of them give reasons for importance.

Suggested answer:

See Chapter 9.2, pages 9.15-16:

Micromachined device technology is a true-born offspring from integrated circuit technology with silicon as the most used material. Micromachined devices are mostly used as sensors and actuators in microelectronics systems, with sensors being the most important. There are several key success factors specific for micromachined devices are [9.1], [9.2]. We suggest the following subjective list:

The top ten success factors of micromachined devices

1. Batch organised planar processing technology offers high quality, low cost, batch organised ways to manufacture micromachined devices. This includes both subtractive techniques such as etching and additive techniques such as thin film deposition.
2. Microelectronics manufacturing infrastructure offers a wide range of advanced services for the manufacture of micromachined devices, e.g. high quality materials such as silicon wafers and photo masks, and sophisticated equipment such as aligners and implanters.
3. Research results from solid state technology and other related fields of microelectronics. This is first of all the accumulated research results of silicon microelectronics, making silicon by far the most investigated electronic material. Advanced research results are also available for other materials used for micromachined devices.
4. Micromachining. Anisotropic, isotropic and selective etching techniques combined with photolithography make high-precision, miniaturised three dimensional structuring feasible. This micromachining capability is first of all achievable with single crystal silicon, but both in principle and practice other materials can be used, e.g. gallium arsenide, quartz or polysilicon.
5. Wafer and chip bonding. To assemble into packaged units, bonding on wafer level or chip level is necessary. Main techniques are silicon-to-silicon bonding, silicon-to-glass bonding and silicon-to-thin film bonding. The techniques can be used for both chips and wafers. Silicon-to-silicon fusion bonding is a high temperature process giving high strength, used primarily for wafers. Anodic bonding is a low temperature process used both for chips and wafers. Other available processes are gluing, soldering and welding.
6. Mechanical material characteristics. The used materials feature favourable characteristics as mechanical materials. Single crystal silicon is here an excellent example, with its high strength and almost perfect elasticity, making it an excellent spring element for sensors and actuators.
7. Sensor effects. The materials used has a large number of physical effects that can be used for signal conversion for sensors, for instance piezoresistivity for sensing in the mechanical signal domain and Hall effect for magnetic signal.
8. Actuator functions. The technology facilitates microscale actuating functions such as micromotors and micropumps.
9. Integrated electronics. Many of the used materials have excellent properties as electronic materials. By combining micromachined devices with on-chip, integrated signal-conditioning electronics, so-called micromachined smart devices, improved or new sensing and actuating methods can be used. For instance, silicon capacitive sensors are very hard to make without on-chip circuit, because both capacitance and capacitance change are in the picofarad range.

10. Combination of features can make very competitive products. Single crystal silicon is in this respect as outstanding. E.g., a silicon micromachined smart pressure sensor [9.2] makes extensive use of these features.

Oppgave 5. Mikromaskinerte komponenter

- a) Sett opp en liste med 5 viktige prosesssteknologier som kan benyttes for mikromaskinerte komponenter, med en kort forklaring på deres virkemåte.
- b) Foreslå en liste med de 10 viktige suksessfaktorer som fremmer utbredelsen av mikromaskinerte komponenter, og begrunn kort hvorfor hver enkelt faktor er viktig.

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