UNIVERSITY OF OSLO

FACULTY OF MATHEMATICS AND NATURAL SCIENCES

Guide for this written examination – also for FYS9260

Exam in: FYS4260 Microsystems and Electronic Packaging & Interconnection Technologies. Also for FYS9260.

Day of exam: Monday, June 3, 2013

Exam hours: 09:00 – 12:00 (3 hours)

This examination paper consists of 6 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 or a combination (For instance using the English words for scientific terms, like “Ball Grid Array”). Use maximum 1 page for each question; that is for each of answers to the a) and the b) questions. 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 svarene hver oppgave, dvs. for hver av a) og b) spørsmålene. Hvert spørsmål vektes likt ved bedømming av svarene.

Question 1: Trends for biomedical electronics & sensors / Lead Free Soldering / Statistical Process Control (SPC) / Failure Mode and Effect Analysis (FMEA)

Background information for question a): Figure 1 shows the concept visualisation for the non-invasive blood glucose sensor nicknamed "GlucoPred" that the Norwegian company Prediktor AS has started developing this year in collaboration with Høgskolen i Vestfold and Østfold Hospital, sponsored by Oslofjordfondet. This sensor shall be used by diabetic patients to enable them to better administrate their eating and/or insulin injections to better keep their blood glucose around a normal value of 5.5 millimol/litre, which is equal to around 100 milligrams/decilitre. The measurement principle is to use sensor fusion by combining multi wavelength near infrared spectroscopy with bioimpedance for improved accuracy.

a) Please comment on what you consider the 3 most important generic technical challenges for Prediktor when developing, manufacturing and marketing such a device for the biomedical market. Another observation is that products used in biomedical applications have a time-limited exception from the restrictions on using lead based soldering, as described by EU's Restriction on Hazardous Substances (RoHS) Directive. Specifically comment for the arguments for the exception, and why it is time-limited.
b) To achieve sufficient miniaturisation, the sensor electronics of the GlucoPred sensor could be made by partly using thick film hybrid electronics. In Figure 2, a thick film substrate with resistors is shown, and we assume we have investigated a production batch of resistors by measuring the values of 100 sample resistors as a part of an SPC survey. Calculate process capability for the thick film process when the resistor value is to be between 112 kohm and 128 kohm, when the mean value is 123 kohm and standard deviation is 2 kohm. We assume that the statistical variations are normally distributed. Is this a process that is in control?

Formula help:

$$Cp = \frac{USL - LSL}{6\sigma} \qquad Cpk = \min\left(\frac{USL - \bar{x}}{3\sigma}, \frac{\bar{x} - LSL}{3\sigma}\right)$$

How can we trim thick film resistors to higher accuracy, and then what do you recommend as a targeted mean value of the resistors after firing and before laser trimming, assuming the above statistical values of the resistors?

Also, perform a quick Failure Mode and Effect Analysis of a typical firing process when manufacturing thick film resistors.

Fig 1: Conceptual schetch of the «GlucoPred» non-invasive blood glucose sensor. The sensor is to be strap mounted on the skin. / Konseptskisse for «GlucoPred» non-invasiv blodsukker sensor. Sensoren festes med en stropp mot huden.

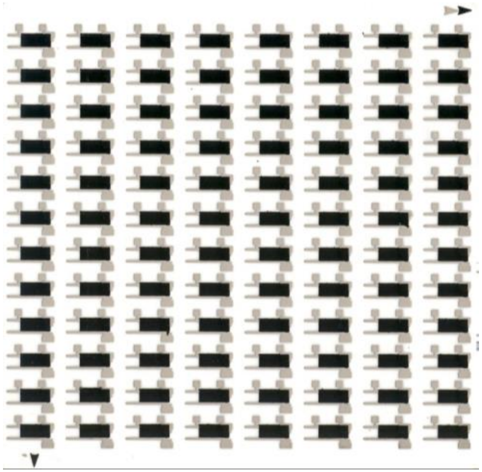


Fig 2: Picture of a substrate with thick film resistors. The resistors are black and the conductor contacts are grey/ Bilde av et substrat med tykkfilmmotstander. Motstandene er sorte og lederkontaktene er grå.

Anbefalt omfang på besvarelsen av denne oppgaven (samlet for a og b) er 2-3 håndskrevne sider.

Oppgave 1: Trender for biomedisinsk elektronikk & sensorer / Blyfri lodding / Statistisk Prosess Styring (SPS) / FeilMode- og EffektAnalyse (FMEA)

Bakgrunnsinformasjon for oppgave a): Figur 1 viser konseptvisualisering for den non-invasive blodsukker sensoren med kallenavnet «GlucoPred» som det norske firmaet Prediktor AS har påbegynt utviklingen av i år i samarbeid med Høgskolen i Vestfold og Sykehuset i Østfold, med støtte fra Oslofjordfondet. Denne sensoren skal brukes av diabetes-pasienter for at de bedre skal kunne tilpasse sin spising og/eller insulin-injeksjoner for holde sine blodsukkernivåer rundt normalverdien på 5,5 millimol/liter, omtrent det samme som 100 milligram/desiliter. Måleprinsippet går ut på å bruke sensorfusjon ved å kombinere multibølgelengde nær infrarød spektroskopi med bioimpedans for forbedret nøyaktighet.

a) Vennligst gjør rede for hva du mener er de 3 viktigste generelle tekniske utfordringene for Prediktor når de utvikler, produserer og markedsfører et slikt instrument for det biomedisnske markedet. En observasjon er at produkter som brukes i biomedisinske anvendelser har et tidsbegrenset unntak fra restriksjonene på å benytte blybasert lodding, som beskrevet av EU’s Restriction on Hazardous Substances (RoHS) Direktiv.. Kommenter spesielt hvorfor dette unntaket er gitt, og hvorfor det er tidsbegrenset.

b) For å oppnå tilstrekkelig miniatyrisering kunne sensorelektronikken til Glucopred sensoren lages ved delvis å bruke tykkfilm hybrid elektronikk. I Figur 2 vises et bilde av et tykkfilmsubstrat, og vi antar vi har undersøkt en produksjonsserie av motstander ved å ta ut 100 enheter som en del av en SPS undersøkelse. Beregn produksjonsgodheten for tykkfilmprosessen når motstandsverdien skal være mellom 112 kohm og 128 kohm, når middelverdien er 123 kohm og standardavviket er 2 kohm. Vi antar at dette er statistisk normalfordelt. Er denne prosessen i kontroll?

   Hvordan kan vi trimme tykkfilm-motstandene til høyere nøyaktighet, og hva anbefales som målsetning på middelverdien på motstandene etter innbrenning og før lasertrimming, når vi antar den overfor gitte statistiske verdier for motstandene?

I tillegg, foreta en rask FeilMode EffektAnalyse av en typisk innbrenningsprosess ved produksjon av tykkfilmmotstander.

Formelhjelp:

$$Cp = \frac{USL - LSL}{6\sigma} \qquad Cpk = \min\left(\frac{USL - \bar{x}}{3\sigma}, \frac{\bar{x} - LSL}{3\sigma}\right)$$

Recommended number of pages for this problem (a and b together) is 2-3 handwritten pages. /
Anbefalt omfang på besvarelsen av denne oppgaven (samlet for a og b) er 2-3 håndskrevne sider.

Proposed Answer:

a) Proposal for some generic technical challenges

Reliability, Product life time, Power consumption/Battery lifetime, Accuracy, Environmental compatibility, (Cost), Health hazards/Regulation conformance (IEC and other regulatory bodies), etc. The candidate should show good judgement when doing this assessment.

RoHS: The time-limited exception from the ban of using lead in biomedical and defence products is due to remaining technical issues when using non-lead solders like tin-cupper- silver soldering alloys or similar solder alloys without lead, giving reduced reliability and shortened lifetime, partly because the solder temperature is around 250 degrees, around 30-40 degrees higher than for tin lead solder with soldering temperature around 210-220 degrees.

b) Cp = (128-112)/(6*2) = 4/3 = 1.3
Larger than 1, but
Cpk = min[(128-123)/(3*2) or [(123.112)/(3*2) = 5/6
which is smaller than 1.

The process is not in control because the actual mean value has a large deviation from targeted mean value. This systematic deviation can most likely be modified and minimised, bringing the process in control, since Ck is higher than 1..
When doing laser trimming, one should start up with a resistor value smaller than targeted value of 120 kohm, typically 20-30% lower, and then trim with online monitoring until target value is achieved. This means that we after firing should have a mean value around 90 - 95 kohm.
FMEA can for instance comment on deviations in the temperatures in the firing oven, contaminated or too old resistor paste, misalignment in the stencil printing machine, and so on.
Commenting on using severity index to give ranked priority for problem solving is good.

Question 2 High speed operation

c) Name and explain the most used geometries to realise transmission lines with controlled characteristic impedance on printed wiring boards and on hybrid circuit substrates. Please use both graphics and text.

d) Calculate the transmission speed for a voltage pulse in a stripline in a printed wiring board or a substrate with respectively PTFE (Teflon) and alumina as the substrate dielectrics. Use the formula $v = c_0/(\sqrt{\varepsilon_r}) = 30\ (\text{cm/ns})/\sqrt{\varepsilon_r}$ with a relative dielectric constant of respectively 2.2 for PTFE and 9.5 for alumina. At first sight, it looks like alumina is unsuited for high speed operation because of the high relative dielectric constant,

Oppgave 2: Høyhastighetsoperasjon

a) Navngi og forklar de vanligste geometrier som benyttes for å realisere transmisjonslinjer med kontrollert karakteristisk impedans på mønsterkort og på hybridkrets-substrater. Benytt både grafisk presentasjon og forklarende tekst.

b) Beregn transmisjonshastigheten for en spenningspuls i en "stripline" leder i et mønsterkort eller substrat med henholdsvis PTFE (Teflon) og aluminiumsoksid dielektrikum. Bruk formelen $v = c_0/(\sqrt{\varepsilon_r}) = 30\ (cm/ns)/\sqrt{\varepsilon_r}$ og relativ dielektrisitetskonstant på hhv 2,2 for PTFE og 9,5 for aluminiumsoksid. Umiddelbart kan det se ut til at aluminiumsoksid er uegnet for høyhastighetsoperasjon pga høy relative dielektrisitskonstant, men bade tykk- og tynnfilmkretser med aluminiumsoksidsubstrat brukes mye til høyhastighetskretser. Forklar hvorfor en allikevel kan få god høyhastighetsoperasjon med slike kretser.

Proposed Answer:

a) See page 6.37 in text book:

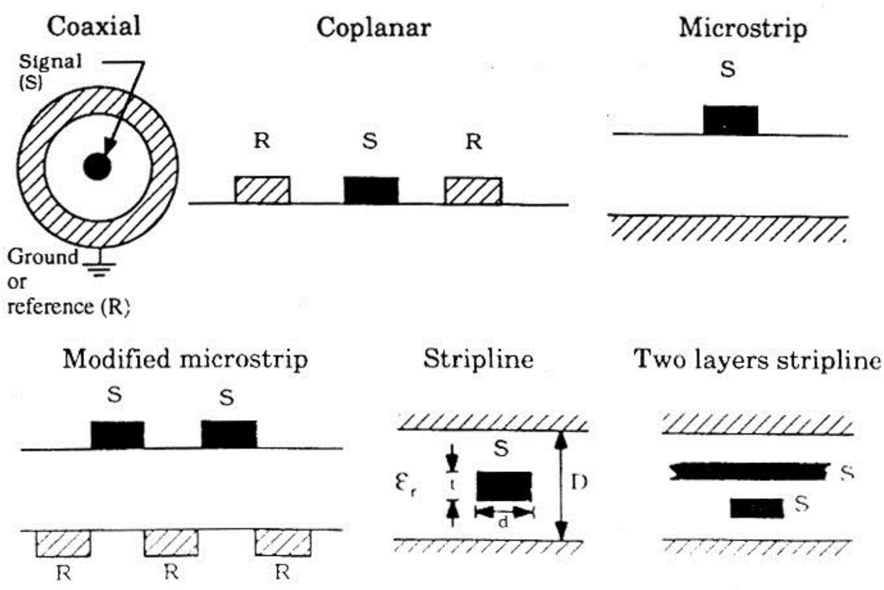


***Fig.** 6.35: Geometries for obtaining a controlled characteristic impedance.*

b) :The transmission speed is given by:

$v = c/\varepsilon_r^{1/2}$

where c is the speed of light in vacuum, ε_r is the effective relative dielectric constant of the media surrounding the conductor, see below. Table 6.11 shows how far a signal travels in 1 nanosecond in different media.

***Table** 6.11: Signal propagation speed in different media.*

$v = c_0/(\sqrt{\varepsilon_r}) = 30\ (cm/ns)/\sqrt{\varepsilon_r}$

Dielectric	*Relative dielectric Constant (ε_r)*	*Propagation Speed (v) (cm/ns)*
Alumina (ceramic)	*9,5*	*10*
Teflon (PTFE)	*2,2*	*20*

As can be seen, alumina does not look like a good high speed material, but when building the circuitry by thick or thin film technologies, the advantage of shorter conductor lines and easier impedance matching often makes alumina a good choice.

Question 3: Wiring boards (Unassembled printed circuit boards) and printed circuit board production

a) Make a cross-section view of a via hole in a two layer through plated printed wiring board that shows the different metal layers, and describe those manufacturing process steps needed for making such through plated via holes when the printed wiring board is produced, by outlining a flow chart with supplemental text for each process step.
b) Explain a common used manufacturing technology for double sided printed circuit boards with exclusively only surface mount components on both sides. This is best done by outlining a flow chart with a supplemental text for each process step.

Oppgave 3: Mønsterkort (Ubestykkete kretskort) og kretskortproduksjon

a) Lag en tverrsnittsskisse av et via-hull i et tolags gjennomplettert mønsterkort som viser de forskjellige metall-lagene, og beskriv ved hjelp av et flytdiagram og tekst de prosesstrinn som må utføres for å skape slike gjennompletterte via-hull når mønsterkortet fremstilles.
b) Forklar en vanlig benyttet fremstillingsmåte for tosidige kretskort med kun overflatemontasjekomponenter på begge sider. Dette gjøres best ved å skissere et flytdiagram og med en utfyllende tekstforklaring for hvert prosesstrinn.

Suggested answer to 3.a:

See Chapter 5.2 «Printed Wiring Boards. General», and see Fig. 5.2.b. and Fig.5.5.

For the process flow, see Chapter 5. «Double Sided Through Hole Mounted Boards»

Suggested answer to 3.b:

See Chapter 7.5 Sequence in the Process of SMD- and Mixed SMD/Hole Mounted PCB's and Fig. 7.44 b.

Anbefalt omfang på besvarelsen av denne oppgaven er 1-2 håndskrevne sider./ Recommended number of pages for this problem is 1-2 handwritten pages.

Question 4: Thin film technology

a. Explain a widespread way of making thin film hybrid circuits. This is best done by outlining a flow chart with a supplemental text for each process step.
b. Point out why thin film technology has a market niche compared to alternative technologies, and give 2 examples of typical applications.

Oppgave 4:Tynnfilmteknologi

a. Forklar en vanlig benyttet fremstillingsmåte for multilags tynnfilmkretser med tynnfilmmotstander. Dette gjøres best ved å skissere et flytdiagram og med en utfyllende tekstforklaring for hvert prosesstrinn.
b. Forklar hvorfor tynnfilteknikk har en markedsnisje i forhold til alternative teknikker, og gi 2 typiske anvendelseseksempler

Suggested answer to 4a:

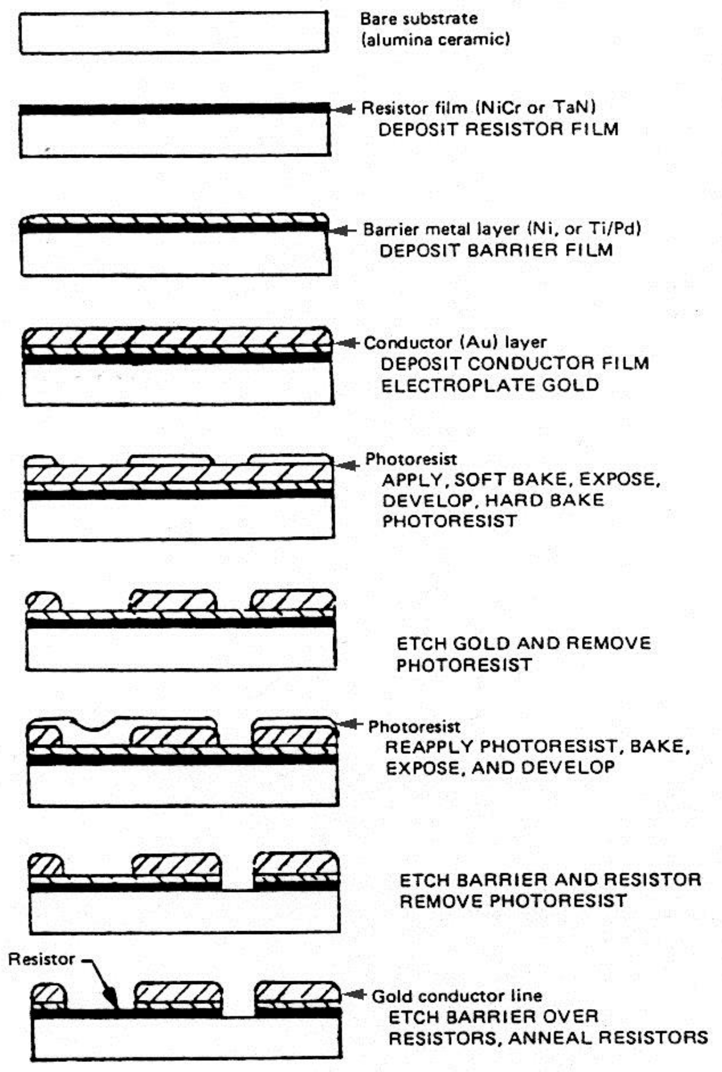
See Chapter 8.4, page 8.18-27:

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 δ 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.

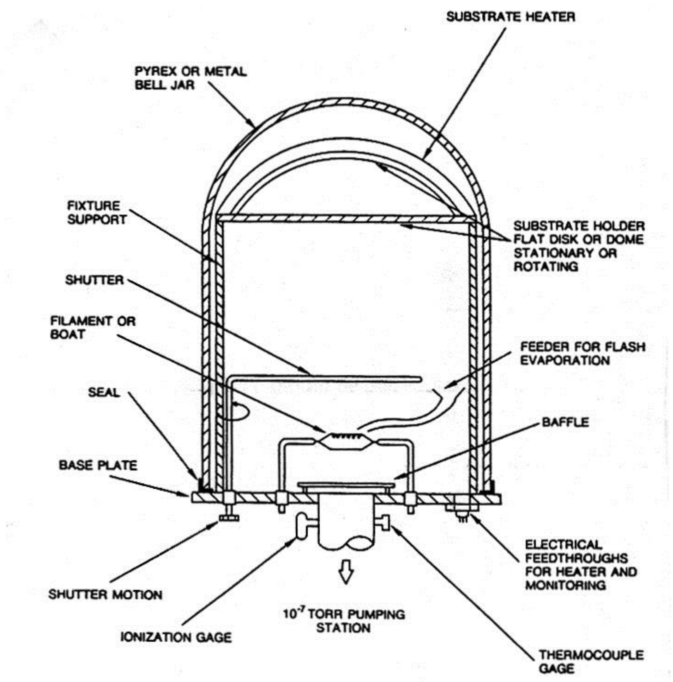
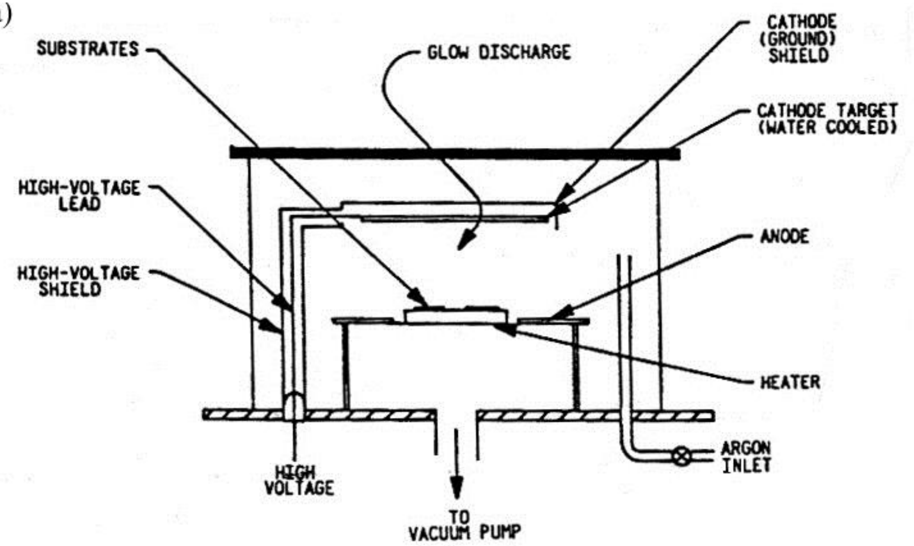


Fig. 3.12: Vacuum evaporation.

a)



b)

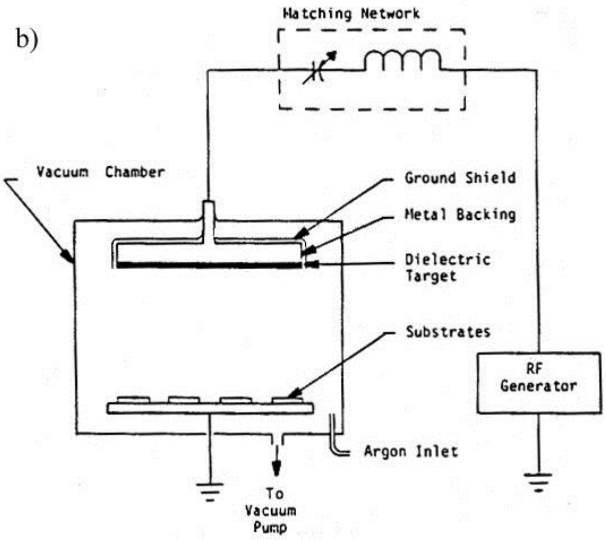


Fig. 3.13: Sputtering: a): DC sputtering, b): Radio frequency AC sputtering [3.8].

Suggested answer to 4b:

Thin film hybrid technology is a high end technology with excellent performance, high reliability, small footprint and relatively high manufacturing costs, best suited for small and medium scale production volumes of products with these features. In this way it is an alternative between monolithic integrated circuit technology with even better technical and reliability features, but with much lower start-up costs (NRE – Non Recurrent Engineering Costs) on the higher end, and thick film hybrid or printed circuit assembly on the low end side. Often we see that thin film circuits are replaced by IC circuits when market success with higher production volumes justifies conversion to IC circuitry.

Examples:

- LCD displays – making use of the transparency of the thin films, like tin oxide conductor pattern.
- Aerospace electronics – with high reliability, low weight and low NRE as important features.

Recommended number of pages for this problem (a and b together) is 2-3 handwritten pages. / Anbefalt omfang på besvarelsen av denne oppgaven (samlet for a og b) er 2-3 håndskrevne sider.

Oppgave 5. Mikromaskinerte komponenter

a) Sett opp en liste med 5 viktige prosessteknologier 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.

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.

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 for 5a:

See Chapter 9.4, 9.5 and 9.6 BATCH PROCESSES ……..

Suggested answer for 5b

See list given in Chapter 9.2. KEY FACTORS TO SUCCESSFUL INDUSTRIAL INNOVATION OF MICROMACHINED DEVICES

Recommended number of pages for this problem (a and b together) is 2-3 handwritten pages. / Anbefalt omfang på besvarelsen av denne oppgaven (samlet for a og b) er 2-3 håndskrevne sider.

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