MIICS 2012

ABSTRACTS

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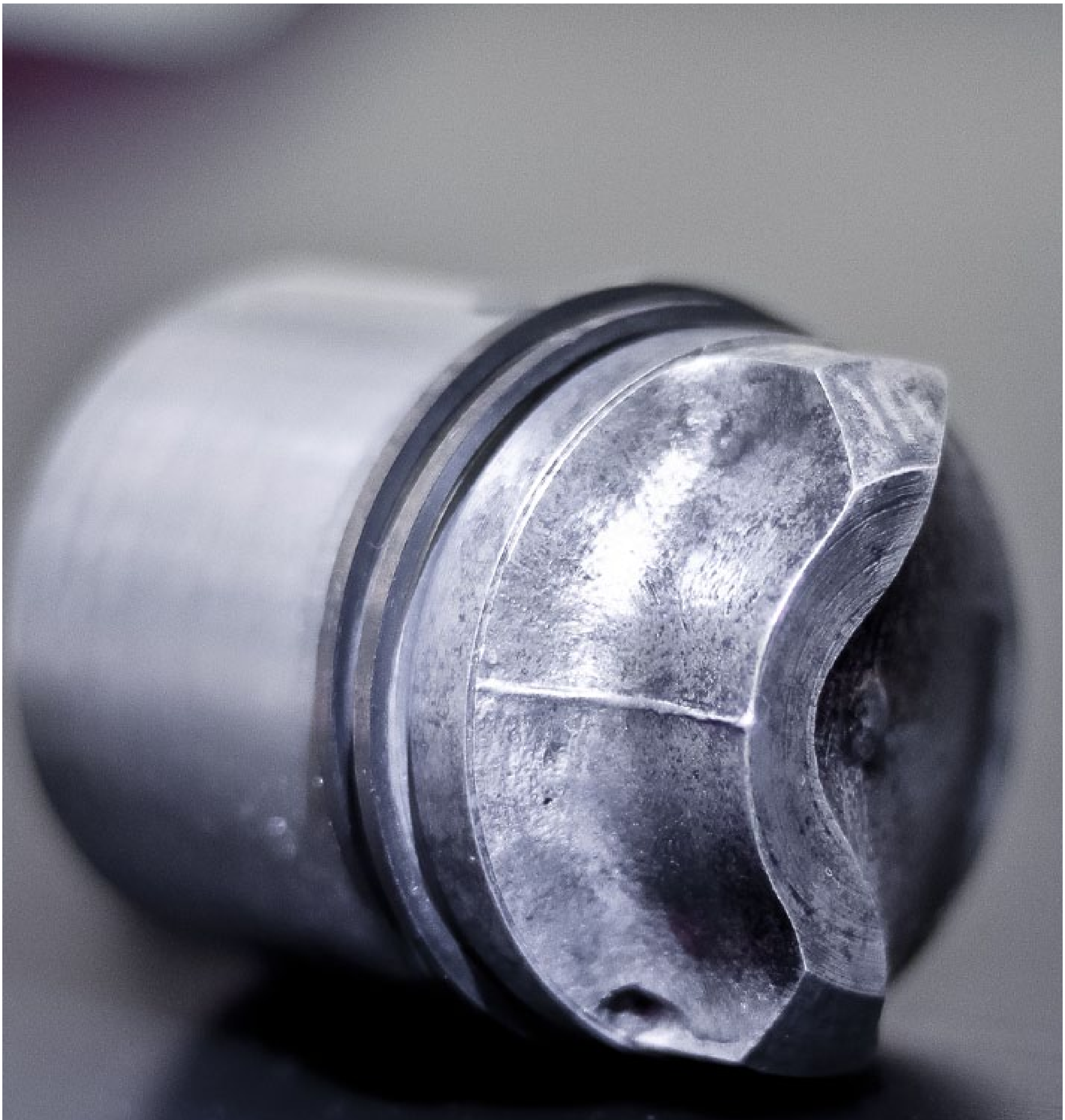

Mikkeli International Industrial Coating Seminar 2012

Opening lecture

FRICTION AND WEAR CONTROL BY COATINGS

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The role of friction and wear in our society is first highlighted by referring to a recent study carried out by VTT and Argonne National Laboratory in the USA on the global fuel energy consumption used to overcome friction in passenger cars. One-third of the fuel energy is used to overcome friction, which equalled to 208 000 million liters of fuel in 2009. By taking advantage of new technology for friction reduction in passenger cars, fuel consumption could be reduced by 18% in the short term (5–10 years). This would equal to worldwide economic savings of 174 000 million euros and CO_2 emission reduction of 290 million tonnes. Potential actions to reduce friction in passenger cars include the use of advanced coatings and surface texturing technology on engine and transmission components, as well as new low-viscosity and low-shear lubricants and additives, and advanced tire designs that can reduce rolling friction.

Coatings are today one of the main techniques to control friction and wear. An overview of the tribological mechanisms determining friction and wear of coated surfaces at different scale levels from nano to macro scale is presented. Computer modelling and simulation of the material response to surface loading has been used successfully to optimise the wear resistance of thin physical vapour deposition (PVD) surface coatings such as TiN, MoS2 and DLC. Parametric analysis was used to develop a new equation for the wear resistance of the coated surface. The problem of wear modelling of thick composite coatings has been approached by finite element method (FEM) modelling on microlevel and stress and strain simulation. Some tens of thousands of carbide particles of various size and shapes extracted from high resolution SEM images of a WC-CoCr coating was included in the model. The model includes real geometrical and mechanical characteristics of microstructural features such as carbide particles, decarburised regions, pores and cracks. The densest part of the FEM mesh around the particle contour details has a node distance of only some 10-20 nanometres. The results are compared to SEM micrograph observations from various loaded regions of WC-CoCr samples that have been loaded in scratch test under similar experimental conditions. Crack initiation and crack growth mechanisms are discussed.

MEASUREMENT OF OIL-FILM PRESSURE AND STRAIN DISTRIBUTION IN ENGINES AND MACHINE ELEMENT COMPONENTS USING THIN-FILM SENSOR

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In the field of engine tribology, there are demands for output, lifespans, reliability and reduced exhaust emissions. In recent years, engine and machinery efficiency improvements have been strongly requested in order to prevent global warming due to CO2 emissions. Engine reliability improvement and friction loss reductions are greatly dependent on the "tribology" of sliding or contact surfaces, such as pistons / piston rings and cylinders, main bearings / crank pin bearings and crankshafts, valve trains etc.. Unit load increases in sliding surfaces resulting from size and weight reductions have caused severe lubrication conditions. In order to investigate their causes, it is important to know the oil-film thickness and oil-film pressure distribution which act on component parts. In the field of calculation analysis technologies, elastohydrodynamic and thermohydrodynamic lubrication theory require accurate knowledge of oil-film pressures and oil-film thicknesses in order to verify boundary conditions. The author has developed 3~6μm thick thin-film sensors, and measured the oil-film pressure distribution of main bearings, pistons and gear tooth surfaces. At the same time, the author has developed thin-film distance sensor, thin-film temperature sensor and thin-film strain sensor consisting of several μm thick layers to investigate the causes of friction loss, wear and noise & vibration. In this presentation, the structure, form and measuring techniques of pressure and strain sensors will be discussed, and some concrete measurement examples will be provided.

FIGURE 1. Application of thin-film sensors for engine parts and machinery (Engine main bearings, Connecting rod bearings, Piston skirts, piston pin-boss, Spur and helical gears, etc..)

FIMECC'S DEMANDING APPLICATIONS CALL FOR ROBUST COATINGS

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Modern industrial applications set high requirements for materials performance and lifetime. Direct costs of material failures, replacements of component parts, increased work and time, loss of productivity as well as indirect losses of energy and increased environmental burden are real problems in everyday business. In catastrophic failures, there is even the risk of human losses.

DEMAPP* program is an active industry driven research consortium developing advanced materials and processing solutions for demanding industrial applications and service environments – high abrasive wear, challenging tribological conditions, corrosive environments, extreme temperatures and heavy cycling loading. The program participants include 25 companies in the metals and engineering industry, their supplier and customer companies as well as 11 high-level research groups in the field. Our working mode is highly co-operative – combining multidisciplinary competences to an active R&D community capable for need-based materials tailoring and effective implementation of results. The common research problems are set by clear application needs defined by the industry partners, while the scientific research creates profound understanding through consistent experimental and modeling work.

The presentation discusses the needs of new materials in demanding applications in engineering, process and energy industry (motivation), describes our unique application-driven co-operation mode (new type of public private partnership), and highlights a few fresh result examples.

* FIMECC Ltd. is the Finnish Metals and Engineering Cluster, one of Finland's new Strategic Centers of Excellence for science, technology and innovation (SHOKs). DEMAPP (Demanding applications, 2009-2014) is one of the research programs that FIMECC has set up to renew the Finnish metals and engineering industry.

COATINGS WITH CARBON NANO MATERIAL

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Functional properties of carbon based thin films as well as carbon nanomaterial are well documented in literature. The versatility of the carbon bonds result into different mechanical, electrical and chemical properties. Novel materials have been processed by combining carbon nano materials with thin films.

Single wall carbon nanotube (SWCNT) networks have been deposited by amorphous carbon films [1]. About 30 nm thin carbon coating on top of SWCNT preserves the excellent electrical conductivity of the network and provides mechanical strength to the network.

The detonation nano diamonds DND have been used as lubricant additives to provide lower coefficient of friction in dry sliding. DND has been embedded into SolGel and DLC thin films. The enhanced tribological properties are reported [2].

1 Antti Kaskela a, *, Jari Koskinen b, Hua Jiang a, Ying Tian a, Xuwen Liub, Toma Susi a,Markus Kaukonen a, Albert G. Nasibulin a and Esko I. Kauppinen, Carbon submitted.
2 Oskari Elomaa et al. to be published

Coatings on flexible substrates

BARRIER LAYERS ON PAPER-BASED PACKAGING

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MIICS This presentation shows how thin inorganic coatings can be used as barrier layers in fibre-based packaging. Basic methods, current state-of-the art technologies and future technologies under investigation are shown and discussed. The vacuum technologies available are compared to a metallization technology; a common process for paper-based structures. Markets show that the typical vacuum technologies available for high-deposition rate barrier production are reactive evaporation to produce Al2O3 coatings, e-beam evaporation to produce SiOx coatings and plasma-enhanced chemical vapour deposition (PECVD) to produce SiOx coatings. The future technologies under development include roll-to-roll atomic layer deposition (R2R ALD), atmospheric atomic layer deposition, atmospheric plasma deposition etc. The water vapour and oxygen transmission rate values measured for the structures indicate that the barrier demands of food packaging can be fulfilled with a single inorganic layer deposited on a polymer-coating covering the paper-based material.

PLASMA-NANO PROCESS FOR DESIGN AND SYNTHESIS OF FUNCTIONAL FILMS ON POLYMER FOR EMERGING INDUSTRIES

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Plasma-nano process for functional film synthesis and surface treatment becomes crucial in development of next generation industrial film materials and devices of unique properties. The prime issue in plasma-nano process development is the control of plasma parameters, chemistry of film materials and surface temperature during film nucleation and growth contributing microstructure and related film properties. The fundamental and application of plasma-nano process is discussed on the design and synthesis of new functional films in terms of material chemistry and plasma parameters preformed in CAPST. The evolution of microstructure including nucleation and growth behavior of functional films is illustrated at various plasma conditions by modulating plasma parameters. The theoretical modeling for surface temperature and film structure design is discussed in terms of plasma parameters including particle flux and energy and compared with empirical data measured by in-situ monitoring of film surface temperature with specified IR measurement system at various pulsed power input conditions. The design and synthesis of functional film synthesis for control of microstructure and bonding control is then illustrated for development of flexible polymer materials. The synthesis and properties of hydrophobic, hydrophilic and hard transparent films is finally demonstrated with process control and corresponding mechanism.

OSKE NANOCLUSTER

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Nanotechnology Cluster Programme has recently gathered new information considering Nanotechnology stakeholders in Finland. A survey on Finnish nanotechnology research reveals the core competences and application areas of 135 Finnish nanotechnology research groups. The most important results of this survey will be discussed - and the brand new Nanoresearch.fi publication will be available for the first time at MIICS. In addition to research stakeholders and emphasis, Nanocluster has recently gathered information on Finnish nanotechnology companies. As a result, the first statistics since the Tekes survey published on 12/2008, describing the current status of Finnish nanotechnology business, will be published in MIICS. The data considering both nanotechnology research and business will be reflected to the Nanocluster services and the best practices of commercialization of nanotechnologies.

STRUCTURAL CHARACTERIZATION OF THIN FILMS AND COATINGS BY X-RAY SCATTERING METHODS

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Advanced thin film materials are nowadays a key technology for electronic, optical, mechanical, chemical and energy supply devices. The characterization and monitoring of structural parameters of thin films is significant for their application. Additionally this information is required to develop and improve thin film deposition technologies.

X-ray diffraction has been applied in research and analytical labs for a long time due to its nondestructiveness and versatility to study structural properties of materials of any kind. In recent years other relevant X-ray techniques evolved to meet the upcoming analytical requirements of advanced materials: high-resolution diffraction, grazing-incidence diffraction, reflectometry, diffuse scattering and small angle scattering. X-ray scattering data deliver information to identify and quantify phases, to determine composition and strain profiles, thickness, roughness, density, grain size and distribution, residual stress and preferred orientation. In the past dedicated instruments were applied for each analysis method, modern lab equipment with exchangeable optics offers all techniques on one single instrument.
In this presentation an overview will be given about the experimental aspects of thin film characterization including recent hardware developments and evaluation process of X-ray methods. Their applicability to extract structural information of advanced layered structures is illustrated on a range of examples of technologically relevant materials.

IN-LINE ATMOSPHERIC PRESSURE ALD OF AL_2O_3 FILMS

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Passivation of front and rear surfaces of solar cells becomes increasingly more important to obtain high solar cell efficiency. High quality, extremely thin films for passivation can be deposited by atomic layer deposition (ALD). The main drawback of conventional ALD systems is the low deposition rate resulting in a low throughput, typically ~50 wph. This is far below the PV industry requirement of >1200 wph. This work demonstrates that it is possible to deposit Al_2O_3 ALD films in a system that is industrially relevant in terms of throughput and passivation capabilities.
In the Levitrack system wafers are floating in a linear gas track at distances of 0.15 mm from the heated top and bottom walls of the track. Gases are injected through a multitude of narrow channels from the top wall down, and from the bottom wall up towards the wafer. The narrow gap results in strong forces that are exerted to the wafer ensuring a stable and contactless movement. After introduction of the wafers, they are heated conductively to process temperature in a few seconds. The wafers pass regions in which one of the wafer surfaces is successively exposed to TMA, N_2, H_2O and N_2. In this arrangement the flow of precursors is constant in time; the wafers being the only objects in the track that move. A typical cell length (TMA, N_2, H_2O, N_2) is 10-14 cm. Deposition of Al_2O_3 on the track walls is prevented by making sure that the TMA and H_2O do not mix while flowing towards the exhausts. Deposition takes place on only one side of the wafer. The system is designed to operate in a temperature window of 150-250°C and to process wafers with a throughput up to 1 wafer/s (3600 wafers/hr). Currently, uniformities of deposited films are in the range of 2-3%. The wafer-to-wafer repeatability of the process is within 1%, and thin films can be deposited in increments of ~1nm.

PROGRESS TOWARDS ROLL-TO-ROLL ATOMIC LAYER DEPOSITION

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The development of a roll-to-roll process for atomic layer deposition (ALD) is one of the biggest goals in the development of a truly industrial-scale process. ALD has traditionally been thought of as a slow batch process with limited throughput. The ability to achieve roll-to-roll capabilities will open up many new market opportunities for high quality ALD coatings such as flexible electronics, specialised packaging, flexible sensor, flexible batteries, etc. ASTRaL in conjunction with Beneq Oy are developing a roll-to-roll ALD system designed for polymer web coating. This system will be delivered later this year. In this talk, some of the technical issues which need to be dealt with in developing a robust roll-to-roll ALD process will be discussed together with some of the research results which have been obtained on moving substrate ALD.

TESTING OF MATERIALS FOR SOLAR EXPOSURE

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Even though UV radiation is only about 5% of total intensity of the solar radiation it causes notable changes e.g. chalking and fading to the material surfaces. Blue Wool Standards are commonly used in the accelerated weather testing to make a connection between the material ageing during the test and in end use environment. Blue Wool Standards (BW) 5, 6 and 7 have all different rate of colour change, higher number indicating better UV stability. On typical sea level situation the UV exposure is ranging from 50 W/m^2 to 80 W/m^2. Known commercially used methods can reach same colour changes in the BW samples in 1000 h than occurs in the nature during one year in Mikkeli. Using the method we have developed this 1000h exposure time can be reduced down to 500h. Besides the wavelength distribution and the energy dose the effect of the sample temperature is important factor to the material ageing.

After the initial UV testing the effect of the other wavelengths in the solar spectrum to the sample can be studied with more advanced methods. According to the intended use of the product the suitable strain method can be developed or exposure can be done according to the standards like IEC 60068-2-5 and MIL-STD-810G.

HIGH TEMPERATURE COATINGS FOR CONCENTRATED COLLECTORS

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Coatings for solar thermal applications have to ensure a good absorption of the solar radiation incident on the absorber, provide a high reflectance in the infrared to reduce the thermal emissivity and protect the substrate material from the ambient atmosphere. In general, these multitask is achieved by a 3 layered optical coating whereby the aluminium or cupper substrate acts as the reflector in the infrared. If, for thermo-mechanical reasons, the substrate is made out of stainless steel, an additional reflection layer, e.g. tungsten, is applied. We developed an optical stack based on $Ti_xAl_ySi_zO_aN_b$. We adjust the composition x, y, z based on the temperature of application. All layers, but the top layer, are deposited by reactive magnetron sputtering. The top layer is deposited by PECVD using a liquid organo-metallic precursor. The absorptance and emissivity the coatings was $\alpha > 95$ % and $\varepsilon < 10$ %, respectively. The optical stack is than tested at temperatures between 290...400°C in air and at 550°C in vacuum aiming for application temperatures of about 300°C.

Solar thermal systems

SOLAR THERMAL DEVELOPMENT IN THE WORLD

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The first patent on the type of flat plate solar collectors used today is from 1909. Solar collectors for water heating were first used in California and later in Florida, until they were overtaken by natural gas, oil and the second world war. Later solar water heaters became an important product in Japan in the 1960's, US experienced a second wave of solar collector development in the 1970's and solar water heaters became obligatory in Israel 1980. Evacuated tube collectors were also introduced in the 70's. After that we have had a strong market development in EU since 1990, while the Chinese market has dominated the last decade by far. The flat plate solar collectors were initially hand made, semi-manufacturing of absorbers together with selective coatings were introduced first in the 70's and more or less fully automated collector manufacturing with robots has dominated the last decade. The largest manufacturers are producing large quantities of evacuated tube collectors i China.

SOLAR DISTRICT HEATING: WHY IS DENMARK LEADING

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During the last years the number of solar district heating systems in Denmark has "exploded". The reason for this explosion is competitive prices of district heat production from large solar collector fields.

The reasons behind the nice development are: (a) Low cost collectors and collector field installation, (b) Increased collector performance and (c) special Danish conditions. The special conditions are widespread use of district heating also in towns in the country side (cheap land available) and constructive interaction with the dynamic liberal electricity market (need for energy storage due to large electricity production by wind turbines). These factors all together results in competitive solar heat production prices. It will be possible to use the Danish experience in other countries - conditions for a successful development are discussed.

SOLAR DISTRICT HEATING IN GERMANY

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Solar district heating especially with long-term heat storage is one of the most promising solar technologies to supply energy for space heating and domestic hot water at a high solar fraction. Since 1996 several pilot plants of different size and with different diurnal and sea-sonal storage were realized in Germany. The latest systems installed are the plants in Munich (2007), in Eggenstein (2009) and Crailsheim (2009). A key-component of such installations is the seasonal heat storage. From the economical and technical point of view, today sensible heat storage in large water tanks, in aquifers (ATES) or in the underground via boreholes (BTES) are favorable but depending on the local geological conditions.

As an example, in Munich approx. 2800 m^2 (aperture) of flat-plate collectors deliver solar heat into the 6000 m^3 underground seasonal water storage as ATES and BTES were not feasible at this location. From there the heat is delivered to 320 apartments via a district heating network. Supplementary heating is provided by an absorption heat pump which is driven by the city district heating system using the seasonal storage as a low temperature heat reservoir. This allows a large operation temperature range of the store between 10 – 90 °C. Direct connection of the district system and the heating installations in the houses avoids typical temperature drops at heat exchangers and increases the temperature spread. The district heating system is operated at a supply temperature of 60 °C with a return temperature of 30 °C which could be proven by the monitoring program. The solar fraction gained in the 2nd year of operation was 45 % and could reach values above 50 % after further optimization.

The strategies to meet the goals of CO2 emission reduction in the heating sector developed in the national Lead Study 2010 as well as the previous versions initiated by the BMU assume a reduction of the heat demand of buildings by approx. 50 %. Half of the left energy demand should be covered by solar, geothermal and biomass which amounts to about 360 TWh/a. This study assumes for 2050 about 45 TWh/a covered by solar district heating. In order to achieve this goal system concepts and technologies have to be developed to introduce solar district heating in the building stock.

The advantages of solar district heating are obvious. For the building stock it is one of the few possibilities to integrate renewable energies and in a lot of cases it is more cost effective than passive house retrofit. The major problem for a fast implementation is still the high initial investment. But if this obstacle could be overcome, the known capital costs together with low maintenance and operation costs can guarantee long-term prize stability for thermal energy.

Solar thermal systems

FLAT-PLATE COLLECTORS — STATE-OF-THE-ART AND TRENDS

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With a total market share of 90 % flat-plate solar collectors are dominating the European solar-thermal market. Nowadays, flat-plate collectors found their path into nearly all low-temperature heating applications, from domestic hot water production and space heating up to process heat for industrial applications. The development of modern selective coatings was a significant step towards a reliable solar-thermal heat production up to 100 °C.

Collector manufacturers are directly affected by the fluctuating raw material prices on the world market, as flat-plate collector mainly consists of copper and aluminium. To cope with the price situation different objects have been pursued. First of all the manufacturers reduced the material thickness of their copper absorbers. This was only possible to a certain extinct as the thickness of absorber plate directly influences the thermal efficiency. The second step was a change from copper to aluminium absorbers with copper piping. During the last years improvements in aluminium alloys enabled collector manufacturers to sell full aluminium collectors. The feasibility of cost efficient volumetric absorber concepts in combination with high selective absorber coatings so far was not possible due to the technical limitations of the PVD and CVD sputtering processes.

The state-of-the-art flat-plate collectors have an optical efficiency of about 80%. The main restriction towards a higher optical efficiency is the transparency of the glazing, which is for heat strengthened low iron glazing $\tau = 92$ %. By applying an antireflective coating on the glazing, this transparency can be enhanced up to $\tau = 98$ %, but comes along with extra costs of up to 10 € per collector.

Well engineered selective absorber coatings do not have such a high potential for development as the absorptivity for sunlit is in the range of $\alpha = 93$-95 % while the thermal emissivity is about $\varepsilon = 4$-9 %.

Besides the high efficient flat-plate collectors manufacturers and research institutes are focusing on low-cost polymeric solar collectors. Cost efficient polymeric materials have a big disadvantage, their restricted temperature and pressure load stability. In this field of research, work is done to reduce temperature loads by applying coatings on absorber and transparent cover allowing a switch from transparent state into an opaque state at a desired temperature.

The contribution to the MIICS 2012 deals with the theory of solar collectors in brief, shows up the collector parts and their function as well as the collector production steps and concludes with the R&D demand for new collector types.