Thin Film
Room: 111 - Session TF+MI-FrM

Thin Films for Light Trapping, Plasmonic, and Magnetic Applications

Moderator: Angel Yanguas

8:20am **TF+MI-FrM1 Designing and Deposition of Multilayer Selective Surface for Tuning Absorption and Reflection of Solar Spectra**, *Z. Ren*, ***Feng Cao***, University of Houston **INVITED**

Spectrally-selective solar absorbers are widely used in solar hot water and concentrating solar power (CSP) systems. However, the performance at high temperatures (>500 ºC) can be further improved. Recent progress on cermet-based solar absorbers has shown promising high temperature thermal stability and wavelength selectivity. Here we explore W-Ni-Al_2O_3, W-Ni-YSZ (yttria-stabilized-zirconia), and W-Ni-SiO_2 cermet based spectrally selective surfaces for high-temperature solar absorber applications. The developed multilayer selective surfaces are deposited by magnetron sputtering on different substrates depending on applications. The absorber consists of two solar absorbing cermet layers with different W-Ni volume fraction inside the dielectric matrix, one or two anti-reflection coatings (ARCs), and one tungsten IR reflection layer for reduced IR emittance and improved thermal stability. All these absorbers show an absortance of > 90% for temperature up to 500 °C and emittance of ~5% at about room temperature and 10-15% at 500 °C.

Recently we are developing a new kind of absorber that reflects a certain range of wavelength and absorbs the rest of the whole solar spectra. The absorbed part is used for electrical power generation by steam engine and the reflected part is used for solar photovoltaic conversion. The thermal energy can be easily stored for later conversion to provide electrical power around the clock without worrying the Sun's night time.

9:00am **TF+MI-FrM3 Femtomagnetism in FePt Nanoparticles for Heat Assisted Magnetic Recording**, *J-Y. Bigot, J. Kim, M. Vomir,* Institut de Physique et Chimie des Matériaux de Strasbourg: Université de Strasbourg and CNRS, France, *O. Mosendz, S. Jain,* ***Dieter Weller***, HGST a Western Digital company **INVITED**

Implementing larger and faster recording capacities, like in Heat Assisted Magnetic Recording (HAMR) devices, requires investigating the magnetization dynamics of nanostructures at the sub-picosecond time scale. The case of $L1_0$ FePt "nanocrystals" is of particular interest as HAMR media can be designed with grain diameter below today's D ~ 8 nm. The magnetic anisotropy is sufficiently high and results in coercive fields larger than 5 Tesla at room temperature [1, 2].

Femtosecond magneto-optics allows investigating the dynamical properties of such films [3] and nanoparticles [4] with a temporal resolution well adapted to the actual needs of performant materials that can be addressed in the time scale of a few picoseconds or faster. In the case of materials for HAMR, the pre-heating with femtosecond laser pulses allows reaching very high electron temperatures beyond the Curie point without over heating the lattice. It is therefore a relevant approach to use femtosecond pulses as it allows improving the conditions for obtaining an efficient switching due to the laser pre-heating. In that context, the variation of the coercive field H_c and magnetization at saturation M_S are important quantities to be characterized. We have investigated such dynamics in $L1_0$ FePt nanoparticles and accurately characterized the nonlinear variation of M_S and H_c upon varying the laser density of energy. We demonstrate that the Curie temperature can be reached during a few hundreds of femtoseconds, showing that the speed for addressing bits of information can be further improved in ultrafast HAMR applications.

[1] O. Mosendz, et al., J. Appl. Phys. 111, 07B729 (2012)

[2] D. Weller et al., Phys. Stat. Solidi A 210, 1245 (2013)

[3] S. Wicht et al., J. Appl. Phys. 114, 063906 (2013) & J. Appl. Phys. 117, 013907 (2015)

[4] E. Beaurepaire, J.-C. Merle, A. Daunois, J.-Y. Bigot, Phys. Rev. Lett. 76, 4250 (1996)

[5] J.-Y. Bigot, M. Vomir, Annalen der Physik 525, 2–30 (2013)

10:00am **TF+MI-FrM6 Application of High Refractive Index Layers to Perfect Absorbers for Solar and Thermal Radiations**, ***Motofumi Suzuki***, *K. Nishiura, S. Masunaka, K. Namura*, Kyoto University, Japan

In this presentation, we demonstrate that high refractive index materials such as β-$FeSi_2$ are key to achieve anti-reflective interference coatings on an opaque substrate. B-$FeSi_2$ is known as an eco-friendly semiconductor and its bulk refractive (n) and extinction (k) indices are higher than 5 and zero, respectively, in infrared (IR) region (λ>1.55 μm). We have reported that the high refractive index of β-$FeSi_2$ is quite useful to reduce the reflectance of metal substrates and that β-$FeSi_2$ thin films/stainless steel substrate systems show nice spectrally selective absorption properties in IR region. For sputtered polycrystalline β-$FeSi_2$ thin films, we recently found that k≈0.3 in IR region, which is different from the bulk value. Thus, we redesigned antireflective-layered structures on an opaque substrate and prepared them. As the results, a system of β-$FeSi_2$/W shows perfect absorption properties, where absorptance reaches higher than 99% at desired wavelength regions, while that in other regions is lower than a few %. On the other hand, another interesting optical property of β-$FeSi_2$ is that both n and k are considerably high in visible to NIR region (λ<1.55 μm). This enables us to design multilayered broadband absorbers for VIS to λ<2.0 μm. The designed multilayers consist of SiO_2/β-$FeSi_2$/SiO_2/β-$FeSi_2$/W, where the upper β-$FeSi_2$ layer absorbs VIS and NIR (λ<1.0 μm) and the bottom β-$FeSi_2$ layer/W absorbs IR (1.0 μm<λ<2.0 μm). The optimized multilayers absorb more than 95% of solar energy and the eminence at 450 °C is lower than 6%. No significant change in absorptive properties in both single and multilayered absorbers has been recognized after they are annealed in air at least up to 500 °C. The perfect absorbers with high refractive index layers are useful for applications to solar selective absorbers for solar thermal power generation and spectrally selective thermal emitters for thermophotovoltaic power generation, IR heaters, radiation cooling.

10:20am **TF+MI-FrM7 Antireflection Coatings for Tandem Solar Cells**, ***Bo Yuan***, University of Delaware, *B. Thibeault,* University of California at Santa Barbara, *K. Dobson,* University of Delaware, *A. Barnett,* University of New South Wales, Australia, *R.L. Opila*, University of Delaware

Because of the ability to exploit multiple absorption bands, Multi-junction Solar Cells (MJSCs) are the most efficient solar cells ever developed. As on single junction solar cells, Antireflection Coatings (ARCs) are utilized to achieve broadband absorption. Due to the fact that the total current of MJSCs is limited by the subcell that has the lowest generated current, ARCs on MJSCs must have the ability to minimize light loss at the range of limiting cell, but optimally all across the visible spectrum.

Unlike conventional Double Layer Antireflection Coatings (DLARCs) that can only reduce light reflection at certain wavelengths, moth eye structures are able to mitigate light loss over broadband wavelength due to their smooth change of refractive index. We report the fabrication of such a Subwavelength Structure (SWS) by using wet etching and dry etching of dielectric materials. Silicon wafers are used here as the substrate to test the quality of ARCs. ZnO has been chosen as one dielectric material because of its excellent transmittance and durability. It also has a close index match to the underlying GaInP window layer in this tandem cell. Wet etching using oxalic acid has been utilized here to texture the ZnO surface because it is a simple and cost-effective method. A low reflection (less than10%) over a broad range of wavelength (400-970nm) has been achieved. However, it turns out that wet etching is not very controllable and cannot fabricate the high aspect ratio periodic structure necessary for optimal absorption. A $Zn(C_2O_4)$ $2H_2O$ bulk phase was found on the ZnO surface.

Thus, lithography and plasma etching have been employed because of their better process control capability and less dependence on the crystalline orientation of the material. We then switched to using Ta_2O_5 since it has similar optical properties to ZnO and also a broad bandgap to ensure its transparency. Dry etching of Ta_2O_5 gives us nanocones with aspect ratio (height over base diameter) of 1.26. At an angle of 8 degree from normal incidence, textured Ta_2O_5 achieved the averaged reflection as low as 6% over 320-900nm and itoutperforms DLARCs and textured ZnO over a wide range of wavelength. Future work will focus on fabricating this moth eye structure on III-V/SiGe tandem cells and simulating the reflectance spectra using Finite Difference Time Domain methods.

10:40am **TF+MI-FrM8 Preparation and X-ray Characterization of Highly Oriented Magnetic and Magnetoelectric Thin Films**, ***Radomir Kuzel***, Charles University in Prague, Czech Republic, *J. Bursik, M. Soroka, K. Knizek*, Academy of Sciences of the Czech Republic

Different kind of thin films with remarkable magnetic and magnetoeletric properties require strong preferred orientation in order to utilize strong anisotropy of their properties.

The main aim of the work is to prepare the films of hexagonal ferrites showing magnetoelectric effects. There are several types of these materials marked as e.g. M-type [$(Ba,Sr)Fe_{12}O_{19}$, space group $P6_3/mmc$], Y-type [$(Ba,Sr)_2Me_2Fe_{12}O_{22}$, s. g. R-3m], Z-type [$(Ba,Sr)_3Me_2Fe_{24}O_{41}$, s. g.

$P6_3/mmc$], and others. Our attention was focussed mainly to Y-type where the best properties are expected. All these lattices are long along *c*-axis and this should be oriented perpendicular to the surface. The films were prepared through the chemical solution method either on $SrTiO_3$ (111) or sapphire Al_2O_3 (0001) substrates, respectively. We are looking not only for suitable substrates but also we have succeeded in using seed template interlayers, for example M hexaferrite $SrFe_{12}O_{19}$. A detailed inspection revealed that growth of seed layers starts through the break-up of initially continuous film into isolated grains with expressive shape anisotropy and hexagonal habit. Promising type of such seed layers seem also to be $SrAl_{12}O_{19}$ films where two kinds of preparation were investigated – deposition of $SrAl_{12}O_{19}$ onto sapphire substrate and reaction $SrO + Al_2O_3$.

Other type of magnetic films studied were magnetic spinels Co_3O_4 prepared by decomposition of films of layered cobaltates Na_xCoO_2 deposited by chemical solution deposition method and grown on sapphire substrates.

The films were characterized mainly by AFM and by several XRD techniques. Phase transitions and thermal stability were studied in symmetric Bragg-Brentano geometry, degree of preferred orientation by rocking curves (omega scans) and phi scans of asymmetric reflections, pole figures and also by reciprocal space maps. Residual stresses were also tested but they were usually zero or negligible. All the films were strongly oriented with the planes parallel to the surface but different kind of in-plane orientations was observed often structures with with several domains.

11:00am **TF+MI-FrM9 Size Effects on the Order-Disorder Phase Transition Temperature in FeNiPt Nanoparticles**, *G. Sutherland, D. Wood,* Brigham Young University, *A. Warren, K. Coffey,* University of Central Florida, ***Richard Vanfleet***, Brigham Young University

Chemically ordering metal alloys such as FePt are hard magnets and good candidates for magnetic data storage in their ordered phase but not in the disordered state. The order-disorder phase transition temperature is impacted by the size of the particle with surface energies becoming significant for nanometer sized particles. Theoretical and computational approaches have predicted lowering of phase transition temperatures as the particle size decreases. Experimental evidence is more limited. Observation of ordering in nanoparticles is a complex interplay between thermodynamic and kinetic factors. Using Fe-Ni pseudo binary alloys with Pt allows isolation of thermodynamic variables. We see a size dependent reduction of order-disorder temperature in this system with particles in the 5 – 12 nm range. At 6 nm the reduction is ~15%

11:20am **TF+MI-FrM10 A Comparison of Heptane Solvent Annealing versus Thermal Annealing Block Copolymers for Bit Patterned Advanced Media**, ***Allen Owen***, *A. Montgomery, H. Su, S. Gupta*, University of Alabama

Hard disk drive storage media is trending towards both smaller physical size and greater storage capacity by increasing the areal density of the magnetic storage media. Bit patterning shows potential as a method for increasing this areal density. A block copolymer template can be used to provide an etch mask for bit patterning a magnetic thin film. Statistical designs of experiments were carried out comparing the effect of nanopatterning via ion milling Co/Pd multilayers using two different annealing methods for PS-PFS block copolymers. The design of experiments for each annealing method varied the etch angle, etch time and etch power during ion milling. Wafers that were sputter-deposited with Co/Pd multilayered thin films were spin-coated with PFS block copolymer and solvent annealed under heptane vapor in an oil bath at 35 °C for 6 hours. Identical wafers were thermally annealed in atmosphere at 140 °C for 48 hours. After annealing, the films were ashed in oxygen to remove the PS, leaving the PFS spheres as masks for the subsequent ion milling. The results from each annealing study showed that nanopillars with a nominal size of ~ 30 nm have been fabricated. The thermally annealed Co/Pd multilayers yielded a 407% increase in coercivity to ~6.6 kOe, while the heptane annealed thin film resulted in a 223% increase to ~4.2 kOe. A statistical design of experiments comparing two different etch techniques:(i) inductively coupled plasma reactive ion etching (ICP-RIE) and (ii) ion milling was carried out for these two annealing methods. The results indicate that process optimization can be achieved with a combination of the correct annealing and etching techniques.

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