Advanced Materials for High Performance Disk Drives

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Future trends in disk drive technology continues to put more stringent demands on materials. In the case of substrates there is a need for higher specific modulus materials for high end files which now have rotation speeds to 7200 rpm's and future design criteria to 14,000 rpm's. In addition, harder surfaces for these high end files will have an advantage for the ruggedized handling of the drives. These requirements are creating a demand for alternatives to aluminum which demonstrate a high specific stiffness in order to minimize overtone and fluttering at the high rotation speeds. There are numerous companies discussing entry's in alternatives which include mixed metal matrix composites such as Al/Al_2O_3 and Al/SiC as well as SiC and various forms of AlB_4C, both reacted and as simple mixtures. The mechanical properties of all these materials being offered vary widely and in addition to densities which vary from about 2.5 g/cc to materials with densities greater than 6.0 gm/cc. Even though density is not a critical issue in an of itself, the specific modulus of all the materials is important for considerations such as stiffness, fundamental resonance frequencies and harmonic overtones, the latter being excited by disk pack rotation and is particularly important as the rotation speeds increase to greater than 10,000 rpm's.

In addition to the above considerations for high rotation speeds in the larger capacity drives it is becoming more important to have media and hence the substrate with a durable surface to withstand the effects of handling.

In this paper we will describe the chemistry of an advanced reacted metal matrix composite which offers a solution to the high rotation issued as well as a durability equivalent to glass.

The material being developed by The Dow Chemical Company consists of aluminum-, boron- and carbon-containing phases which are produced in-situ as a result of chemical reactions between boron carbide and aluminum. The unique feature of the material is its tailorability with a specific stiffness about 4-5 times higher than the currently employed aluminum. By varying composition and processing, it can be produced with properties and microstructures designed for the specific applications with density ranges from 2.57 to 2.68 g/cc, stiffness from 200 to 380 GPa, hardness from 600 to 1500 kg/mm^2, flexure strength from 500 to 650 MPa, and fracture toughness from 5 to 10 $MPa\bullet m^{1/2}$. The presence of metal improves dampening and provides excellent electrical conductivity, both of which are properties of interest for alternative substrates.

Other Aluminum Boron Carbide (AlBC) disk drive components are currently under development and include spacers as well as actuators. The general method of production of the substrates and components is based on ceramic processes similar to those used to produce IC substrates for the semiconductor industry: green tape production with punching or injection molding with subsequent firing. In the case of AlBC a new step has been added, i.e. reaction of aluminum metal to produce the AlBC materials.

Due to the type of chemistry it is possible to produce a variety of "different" materials which are manifested with varying modulus; fracture toughness, etc. Since hardness and stiffness are critical properties, it is important to understand that these properties are controllable. As can be seen it is possible to produce a modulus range from about 100-400 GPa which translates to a controllable stiffness and fundamental resonance frequency, the latter being calculated by Equation 1

$$f_n = \frac{\lambda_n t}{2\pi a^2}\sqrt{\frac{E}{12\rho\left(1-\nu^2\right)}} \tag{1}$$

with the boundary conditions where

$$\lambda_n = 3.75 + 8.81\left(\frac{b}{a}\right) + 5.00\left(\frac{b}{a}\right)^2 + 48.75\left(\frac{b}{a}\right)^3 \quad \text{for} \quad 0.0 \le \frac{b}{a} \le 0.5$$

and a and b are the outer and clamping radius, respectively. This is shown for the 95 mm substrates employed for high end applications.

<u>Substrates</u>

Substrate stiffness and resonance frequencies are critical parameters for the 95 mm form factor media and it is important to understand the importance of specific modulus, which is denoted by E/ρ, is to these two properties. Simplified forms of these two parameters are shown in Equation 2 and 3 below. Expanded forms of these expressions used for detailed modeling are available (1) but for the present discussions these reduced forms will suffice.

$$S \propto E/\rho \; t^3 \tag{2}$$

$$f_n = \frac{\lambda_n t}{2\pi a^2}\sqrt{\frac{E}{12\rho\left(1-\nu^2\right)}} \tag{3}$$

It is also important to note that the stiffness is dependent on the cube of the thickness. As can be seen by the reduced equations, E/ρ is very important and is represented for all the competitive materials with the currently employed aluminum in comparison to the alternative high performance materials such as AlBC and SiC. This specific stiffness denoted as E/ρ can also be modeled to represent the relative difference in various substrate materials as a function of specific modulus and thickness.

The stiffness or deflection as shown is function of thickness and specific modulus for a 95 mm disk in the configuration shown. As can be seen the higher E/ρ materials allow the use of much thinner substrates if there is a need and hence the potential of higher media population for a specific drive height. Another important consideration for high end drives is fundamental resonance and overtones, the former being described in Equation 3 which is solved for varying specific modulus' and shown. As can be seen, the fundamental resonance frequency is dramatically affected by varying E/ρ.

Naturally, the controlling property for stiffness, fundamental resonance, and overtone harmonics is specific modulus, which ranges for the materials in question about 26 GPa for Aluminum to a high of >100 GPa for most of the ceramic type materials including SiC and AlBC. A comparison of E/ρ for the candidate materials is shown in the Table.

It should be obvious that if stiffness and resonances are the issues, materials like SiC and AlBC should be the preferred candidates. An example of this is shown where the frequency of Dow's AlBC is compared with a standard Al substitute in a 95 mm configuration, 31.5 mils thick. In addition, AlBC with its variable modulus from about 250-350 GPa also allows flexibility in drive design; this is shown by the highlighted areas in the figure.

A number of these options are currently being explored which include the zirconia substrate by Norton, SiC by a number of companies the mixed metal matrix composites previously mentioned as well as the Ni overcoated AlBC entry by Dow Chemical. Naturally, there are pro's and con's for each and it remains to be seen which material will be able to be finished at a competitive price. Regarding the finishing issue Ni plated has the advantage in that this technology requires at typically hardness of substrate materials results in the long finishing times with the exception of the Ni/AlBC which requires standard Ni deposition and finishing technology. In addition, the post processing of the Ni plated AlBC allows standard mechanical as well as laser texturing with identical equipment that is currently used for the Ni plated Aluminum.

Another issue with alternative substrates is media deposition and stability. Even though some companies have been successful in coating the alternatives, many have had problems therefore the interchangability issue is important. In addition to the above issue there is a concern for stability, particularly under adverse environmental conditions such as elevated temperatures and humidity. This has been suggested as a result of the substrate, or better stated, the lack of chemical stability of the substrate material. In the case of Ni plated AlBC it isn't an issue.

In addition to calculating the fundamental resonance frequency, it is possible to make a static and dynamic measurement of this property. The former shown in both free standing and clamped configurations. As can be seen, the fundamental resonance of AlBC at ~900 Hz is significantly greater than aluminum at < than 500 Hz. The dynamic measurements were made on the 95 mm substrates. As can be seen, in comparison with Aluminum the fundamental frequency is about 50% higher with an amplitude of approximately 1/10 of the Al. The result of this higher resonance condition and lower amplitude also allows increased flexibly in designing around overtones at rotation speed's to >10,000 RPM's.

<u>Actuators</u>

The same property that is important for substrates, namely stiffness, is of equal importance with the actuators for the high rotation, high TPI drives. One issue with AlBC, which is totally elastic, is fatigue under repetitive cycling at elevated temperatures and humidity.

In view of this concern, representative "support" samples were tested for fatigue from heating and cooling and humidity, these parts were tested with the configuration shown which supported the actuator arm samples at their base location while inducing a tip

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1) S.P. Timashinko and J.N. Goodier, Theory of Elasticity (Rev. 3), McGraw-Hill, Inc., Reissue 1987.

deflection from zero to a positive value through tip contact with a dynamic shaker reciprocation element. Loading was performed at 60 Hz, with displacement magnitudes monitored via LVDT. Though this configuration does not introduce a complete stress reversal ($R=\sigma_{min}/\sigma_{max}=0$), it does simulate conditions encountered during drive use, as the support arm/suspension/slider assembly is not constrained to remain in contact with the disk surface. Tip displacement values versus loading cycles characterize the fatigue lifetime/endurance limit. Failure was detected though measurement of electrical continuity across the specimen. The brittle fractures which did occur during fatigue failure were initiated predominately in the vicinity of the through hole geometric features which introduce regions of stress concentration. Static deflection level to fracture was determined by deforming the sample geometry in a single cycle until fracture was observed. The results of those experiments are shown and as can be seen there is no effect of humidity or temperature cycling.

By comparison it is possible to employ numerical simulation to lend insight to experimentally derived results. Although a portion of the aluminum within Al-B-C composite microstructures remains unreacted, deflection behavior to fracture levels is considered to be linearly elastic due to the predominance of ceramic phases within the bulk volume. Specific material properties ($\nu \sim 0.20$, $E \sim 277.8$ GPa, $\rho \sim 2.62$ gm/cm^3) for the prototype specimens selected for this test were employed to predict (a) 1st bending mode resonance frequency and (b) maximum stress distribution within the part when subject to the peak tip deflections which were encountered during the high cycle fatigue measurements of as shown.

These results are compounded with computed bending resonance frequencies of both stainless steel and Al-B-C to experimentally derived values of Al-B-C. Though the predicted values differ from the as-received specimen average of 2785 Hz by 9.1%, slight inaccuracies in numerical simulation of boundary conditions actually experienced during experimentation are expected to occur and could account for the discrepancy. It is evident from the differences illustrated, that Al-B-C would clearly offer a more stable platform over stainless steels for suspension/slider assemblies during operation. The contrast in resonance with respect to additional candidate materials can be approximated from consideration of Equation 4, which

$$f_n = \frac{3.52}{2\pi}\sqrt{\frac{EI}{\rho A L^4}} \tag{4}$$

where: E= Elastic Modulus
I= Moment of Inertia
ρ= Mass density of beam material
L= Beam Length
A= Cross Sectional Area

represents the first bending mode natural frequency of a uniform cross section beam with a uniformly distributed load, and fixed at one end. For identical geometries, the material dependent $(E/\rho)^{0.5}$ term then dictates relative performance as was discussed for the substrates. Additional torsion modes are expected to contribute to off-track errors; though not measured experimentally, they are estimated to easily exceed 10 kHz for this particular material property combination and geometry.

Another concern with elastic materials such as AlBC is for suspension attachment as swaging isn't an option under the present configuration with these types of materials and epoxy attachment is recommended, although not well received at the present time.

It should be noted that even though AlBC is a completely intractable material when in its final form, fabrication of parts such as E-Blocks is very fundamental with injection molding of the "green" from of the B_4C prior to debindering and infiltration. In this process the advantage of AlBC is that it can be "near net-shape" formed due to extremely low-shrinkage of <0.2% (for reference, typical MIM's have anisotropic shrinkage to 20-25%).

There are many advantages with stiff, non-plastic materials being used at the Head/Disk interface with the two most important issues in the high TPI arena being addressed by the stiffening of AlBC. The first is the Axial Run out caused by either disk pack vibration or interaction between a fluttering disk and the head/suspension. In this particular example, with a very stiff AlBC E-Block or suspension mount the spacing between the head and disk is stabilized as shown. This either allows the use of a thinner mount or one that is stiffer. The second area of impact with a material like AlBC is in the area of radial runout which is predicted to be enhanced due to the stiffness of the lever arm to which the suspension is attached.

SUMMARY

Alternative materials for substrates and actuator/support arms applications offer opportunities to favorably influence drive performance through improved dynamic behavior. Aluminum-Boron Carbide offers advantages in the form of its specific stiffness (E/ρ), electrical conductivity close to that of aluminum, low mass, and processing ease as compared to competing ceramic based candidates. The following summarizes conclusions which can be drawn from this work:

- Al-B-C can be formed through large scale processing techniques to fabricate substrates and support arms of practical/realistic design configurations with typical property levels of interest. Variation in process design allows microstructural tailoring to suit specific application requirements; modulus levels of 380 GPa with similar densities are achievable.
- First substrate overtone with AlBC is significantly greater than that of Al when measured under dynamic conditions with a much smaller aptitude.
- Thermal cycling and relative humidity exposure at elevated temperatures showed negligible effects on both dynamic/resonance and high cycle fatigue behavior for the support arms. A fatigue lifetime of $>50\times10^6$ cycles was found at 0.34 mm tip deflection.
- First support bending mode resonant frequencies vary with $(E/\rho)^{0.5}$; at 2.8 kHz, Al-B-C is approximately 2 times greater than that of the stainless steel, aluminum, and magnesium in current use. First torsion mode frequencies are expected to exceed 10 kHz for this particular material property combination and geometry.

Though substrates and suspension/slider dynamic behavior shortcomings are currently a major hurdle in efforts to reduce off-track errors and ultimately limit the bandwidth of the track following servo, substrates (media) and actuator support structures with increased resonant frequencies are projected to be usable in conjunction with designoptimized geometries which, together, will provide improved stability during operation and lead to an increase in usable track density.