Letters

A technique for the measurement of Young's modulus of small metallic glass samples

Metallic glasses are frequently prepared by the arc-melting piston-and-anvil quenching process [1]; for refractory or reactive metallic glasses [2, 3], where melt spinning is not readily applicable, this technique is presently the principal preparation method. It produces small alloy discs from which rectangular samples with typically ~ 1.5 cm length can be cut. These samples are too short to allow precise measurements of the sound velocity V_E (and thus the Young's modulus E from the relation $E = \rho V_E^2$, where ρ is the density) by the ultrasonic pulse echo (P.E.) technique now generally used for dynamic measurements on long melt spun metallic glass ribbons; accordingly, E values have not been reported for such alloys. It is obvious that short samples are also unsuitable for static determinations of E.

We have applied the impulse-induced resonance (I.I.R.) technique developed by Fowler and co-workers [4,5] to such short glassy metal specimens. This technique uses the same experimental arrangement as that used by us for P.E. measurements of V_E, although our technique for measuring time for P.E. measurements differs from that typically used. An alloy sample is attached to a magnetostrictive Remendur delay line into which a broad-band sound pulse is introduced by a transducer connected to a Panametrics 5055 Pulser-receiver; the latter also activates a Berkeley Nucleonics digital delay generator and an oscilloscope. The physical measurement, however, differs in the two methods; instead of determining the time required for the pulse to traverse the sample, as in the P.E. method, in the I.I.R. technique one initiates an extensional mode resonance in the sample; from the (measured) period T of this resonance and the length of the sample, V_E and hence E can be derived for samples of ~ 10 mm length. With proper procedure (uniform and narrow samples and correct specimen attachment) reproducible well-shaped resonance patterns are obtained which lead to T values precise to ± 0.04%. The uncertainty in V_E is primarily due to the measurements of the sample length and is ± 0.2%, about equal to that for P.E. data, giving an uncertainty of ± 0.4% in E from V_E. An uncertainty in E of the same order of magnitude is due to the density measurement on the available small sample quantities. (It should be noted that the I.I.R. technique is distinct from the "vibrating reed" method [6]. The latter is also unsuitable for short piston-and-anvil glass samples, as a uniform sample thickness is required; the accuracy of E obtained with the vibrating reed technique is estimated to be ~ 10% [6].)

As shown in Table I for $Zr_{0.35}Cu_{0.65}$, V_Es measured by the I.I.R. method on a short, narrow strip from a piston-and-anvil sample and by the P.E. method on a melt spun ribbon are in close agreement, illustrating the validity of I.I.R. results. Also shown are results obtained from two other amorphous metals which are more readily prepared by the piston-and-anvil quenching process than by melt spinning. Melt spinning of amorphous $Ti_{0.60}Ni_{0.40}$ is not readily accomplished because of the reactivity of this alloy (i.e. the resultant

TABLE I Properties of metallic glasses

	Measurement method	V_E (10^5 cm sec^{-1})	ρ (g cm^{-3})	E (10^{11} dyn cm^{-2})
$Zr_{0.35}Cu_{0.65}$ (piston-and-anvil)	I.I.R.	3.47	7.76*	9.34
$Zr_{0.35}Cu_{0.65}$ (melt spun)	P.E.	3.47	7.76	9.34
$Ti_{0.60}Ni_{0.40}$	I.I.R.	4.03	5.90	9.58
$Nb_{0.55}Ir_{0.45}$	I.I.R.	3.27	14.09†	15.06

* Assumed equal to that measured from the melt-spun ribbon.
† Assumed to be 1% less than that of the corresponding crystalline alloy.

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interactions with the crucible) and the high quench rate necessary to achieve the fully amorphous state; melt spinning of $Nb_{0.55}Ir_{0.45}$ is difficult because of the high liquidus temperature of this alloy.

A comprehensive description of the I.I.R. method, its application and limitations, and further data obtained with it will be published subsequently [7]; in the meantime, experimental details can be obtained from the authors.

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Thermal expansion of gallium borate

Recently, Bither and Young [1] synthesized a number of borates under high pressure and high temperature conditions, and found that they belong to $R\bar{3}C$ space group and are isotypic with the calcite structure. A perusal of the literature shows that the thermal expansion of gallium borate which has the same structure as calcite, has not been so far studied. As the authors have determined the precision lattice parameters and the coefficients of thermal expansion of a number of carbonates [2–5], nitrates [6, 7] and borates [8, 9], it is thought worthwhile to include the borates synthesized by Bither in the general programme of X-ray investigation on calcite-type compounds.

The sample used in the present study was kindly supplied by Professor Bither, Central Research Department, E.I. du Pont de Nemours and Company, Experimental Station, Wilmington, Delaware, USA. It was found necessary to heat the sample to 600° C to obtain well-resolved sharp lines in the high-angle region. The sample for study was prepared by filling the powder in a thin walled quartz capillary. Using Cu*K* radiation, powder photographs at different temperatures were recorded in the temperature range 38 to 900° C. Temperature control was facilitated by the use of voltage stabilizer and a variac. The temperature could be held constant within about 2° C. Details of the experimental technique and the method of evaluating the precise lattice parameters and the coefficients ot thermal expansion has been described in an earlier paper [2].

Reflections from $(1.2.14)_{\alpha_1}$, $(1.2.14)_{\alpha_2}$, $(2.2.12)_{\alpha_1}$, $(2.2.12)_{\alpha_2}$, $(416)_{\alpha_1}$, $(416)_{\alpha_2}$, $(329)_{\alpha_1}$ and $(329)_{\alpha_2}$ in the Bragg angle region 65° to 80° were used to evaluate the lattice parameters at different temperatures. In evaluating the lattice parameters independent measurements and calculations were made on several films and the average of the deviations of the individual values from the mean was taken as the error in the lattice

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