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Mechanical investigation on macro wire of Bismuth samples

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Abstract: Bismuth is a semimetal in bulk, bulk material do not having a good thermal as well as electrical properties, but Bismuth nanowires (10nm) have a good thermal and electric behavior while nano wire exhibiting semiconducting behavior. Mechanical characterization is critical for the formation of nanowires made of various materials. The attempt is made to prepare the nano wires of Bismuth. The microhardness testing of bismuth wire plate samples was performed. Using Indentation Size Effect (ISE) Model different mechanical parameters on a microscopic scale were calculated and presented in this communication. Vicker's mircohardness number (Hv) variation with load were reported. At small indentation test loads, an indentation size effect was observed for Bismuth wire plate samples. For all samples, the variation of microhardness number (Hv) with variable loads is non-systematic. PSR (Proportional Specimen Resistance) Model used for obtaining the more relevant microhardness data are also summarized in present communication. The calculation of elastic stiffness constant C11 obtained through Wooster's empirical relations.

Keywords: Vicker' Microhardness, Bismuth, Indentation Size Effect (ISE), Proportional Specimen Resistance (PSR)

1. INTRODUCTION

Bismuth nanowires have a good thermal as well as electrical properties and exhibit semiconductor behavior. Bismuth nanowires are useful as a fuse in infrared optics and provide an excellent opportunity to investigate the effect of quantum confinement. These mechanical studies are useful and helpful in the formation of crystalline bismuth nanowires. Microhardness testing of bismuth wire plates were performed on a microscopic scale .Microhardness testing is a non-destructive method for determining the suitability of a material for a given purpose. Microhardness testing was performed on 5N pure bismuth wire plate samples. The behavior of variation in microhardness number (Hv) with load changes is non linear way. Mayer's index 'n' was also discovered, and its value for bismuth metal is less than 2; this indicates that the material is soft and extremely ductile.

2. EXPERIMENTAL

5N pure Bismuth was obtained from Nuclear Fuel Complex, Hyderabad. Macrowire of bismuth material was prepared by melting the bismuth metal in the thistle and end of thistle was connected to 1 meter long and 1 mm diameter wire wounded capillary. The current supplied to obtain the melting temperature of Bismuth material. The molten melt moves in capillary and after cooled it slowly a very fine nearly 20 cm long wire was obtained as shown in Fig.1. The wire was sliced by thin plates and indentation marks were made using Vaisheshika Vickers Microhardness tester. Indentation marks were made with a pyramidal diamond indenter. The measurements were carried out for load ranging from 10 gm to 120 gm for all samples and the indentation time kept constant and it was 10 seconds. Randomly different indentation marks for constant time were made for different load values on smooth surface of Bismuth plates. The mean diagonal length was used in calculations. Vickers microhardness number (Hv) is obtained for each samples. To obtain the general behavior, the average of 20 samples at each load were drawn on single graph of Hv vs P. Vickers microhardness were obtained through following relation

$$Hv = 1.854\ P/d^2\ Kg/mm^2 \qquad (1)$$

Where P is the applied load in Kg and d is average diagonal length of indented impression in mm. Hv is in unit of Kg/ mm². The Moh hardness H_M is calculated through Mott formula for respective samples,

$$H_M = 0.657\ (Hv)^{1/3} \qquad (2)$$

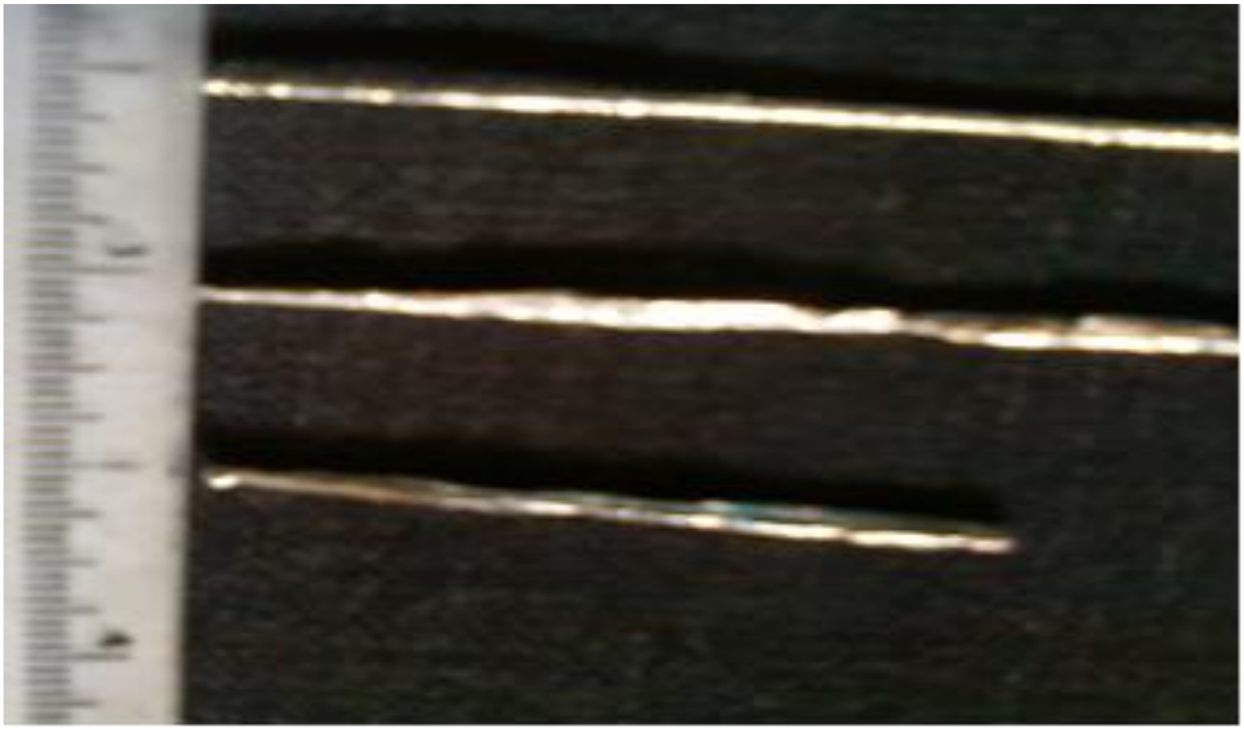

Fig. 1. Photograph of bismuth Wire

Table 1. Values of Load Independent hardness (Hv°) Kg/mm², K1 and K2 from ISE,a1, a2 and Hv° from PSR Model

Sample	Hv Kg/ mm²	Work-Hardening-Coefficient 'n'	ISE parameterK 1	ISE Parameter K2	Stiffness constant C11 x 10^{11} N/mm²	Load Independent Hardness Hv°	PSR Parameter a1	PSR Parameter a2
Wire Plate Samples	14.297	1.963	0.0091	0.0036	0.103	13.40	0.0512	70.8

3. RESULTS AND THEIR ANALYSIS

The variation of Vickers microhardness number Hv is function of applied load for Bismuth wire plates and shown in Fig.2 . It is evident from the Fig.2, that Vickers microhadness number Hv decreases with increase of load at small load values and then it increases with higher load , it becomes constant at high values of load. The microhardness decrease with increase of load is in good agreement with the normal Indentation Size Effect (ISE) [1-4] . Several models for the relationship between applied indentation test load and indentation diagonal length have been reported in the literature to describe the ISE behaviour of material. Intrinsic structural factors of the test material [5,6,7] are the most common explanation of ISE found in literature.

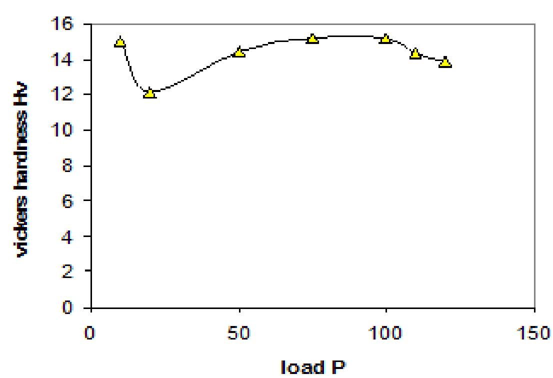

Fig. 2. Hv vs P gm

In order to analyze the ISE in the hardness testing one needs to fit the experimental data according to Meyer's law, which correlates the resulting indentation size d and applied load P with each other,

$$P = K1d^n \quad (3)$$

Where K1 is the material constant (standard hardness), n is the Meyer index and other symbols have their usual meanings. Fig 3 illustrating the plot of log P against log d for bismuth wire plates samples, is in good agreement with Meyer's law.

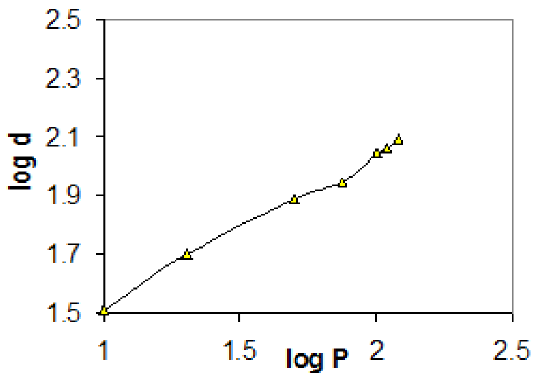

Fig. 3. logP vs log d

Combining equation (1) and (3) we get

$$Hv = K2P^{n-2/n}$$

Here K2 is a new material constant. This expression shows that Hv should decrease with increase in P if n < 2., which is in good agreement with the experimental data because the value of n. The value of n calculated using least square fitting method was found to be less than 2 for bismuth wire plate samples as shown in table-I.

According to Onitsch [8] and Hanneman [9] , n should lie between 1 to 1.6 for hard material and above 1.6 for softer ones. The value of n for all samples are above 1.6 so, it suggests that our samples belong to soft material category. Recently Li and Bradt explained the ISE with help of general model "Proportional Specimen Resistance" (PSR). As can be seen from Fig 2. Hv for all Bismuth samples attains saturation value at higher load can be explain by PSR model. According to PSR model, there are two factors which are responsible for decrease of Hv with increase in load. These are (i) the frictional forces between the test specimen and indenter facts and (ii) the elastic resistance of the test specimen. In the PSR model Li and Bradt, microhardness can be described by two different parts,

(a) The indentation load dependent part or ISE regime and
(b) The indentation test load independent part. The indention test load (P) is related to indentation size d (Li, Bradt) [10]

As $P = a1d + a2d$

$$= a1d + (Pc/d0)\,d^2 \qquad (4)$$

a1 – coefficient is contribution of proportional specimen resistance to apparent microhardness
a2 - coefficient related to load independent microhardness
P – the critical applied test load above which microhardness become load independent
d0 – the corresponding diagonal length of the indentation equation (3) can be rearranged as

$$P/d = a1 + (Pc / d0^2)d \qquad (5)$$

i.e. a Plot P/d against d will give a straight line as shown in fig.3 ,the slope of the plot the value of load independent microhardness (Hv°) for Bismuth wire plates shown in table-I. Applying PSR model of Li and Bradt [6] in the case of Bismuth samples have been observed the plot of p/d against d conform that PSR model is also applicable for bismuth wire plate samples. The slope of plot P/d against d give the value of $Pc/d0^2$ which when multiplied by Vickers conversion factor 1.854 gives load independent microhardness. Table-I summarized the Vickers microhardness as obtained from equation (1) along evaluated from the slopes of graphs. Wooster's empirical relation [11] used to calculate first order elastic stiffness coefficient C11 shown in table –I.

$$\log C11 = 7/4 \log Hv° \qquad (6)$$

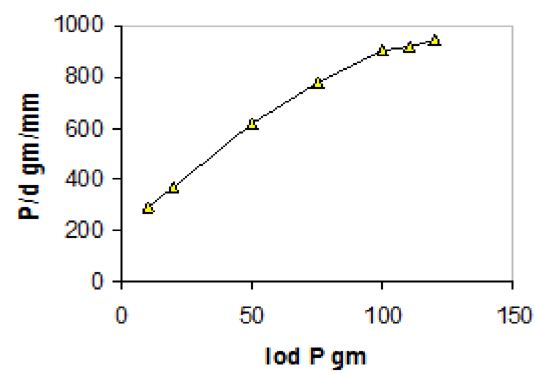

Fig. 3. P/d s d

4. CONCLUSIONS

Bismuth wire of 20 cm long and 1mm diameter obtained . Microhardness measurement of Bismuth wire plate samples are calculated and Vickers hardness number (Hv) is in the range16-19 kg/mm² under the applied load in the region of 10-120 gm. The decrease in hardness with increase in load is in good agreement with ISE. The variable hardness for different faces at different planes defined as microhardness of Bismuth crystal is influenced by anisotropic properties of crystals. The microhardness behavior for the different crystal planes is different for initial smaller value of applied load but the indentation on all these samples resulted in a region where the microhardness is independent of applied load and these are well fitted with the approach of Proportional Specimen Resistance (PSR) model[6]. Work hardening coefficient found to be greater than 1.6 for bismuth wire plate could be concluded that bismuth is soft material and extremely ductile and also suggest that there is a possibility in decrease of wire's diameter of bismuth.

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