Anisotropic thermoelectric devices made from single crystal semimetal microwires

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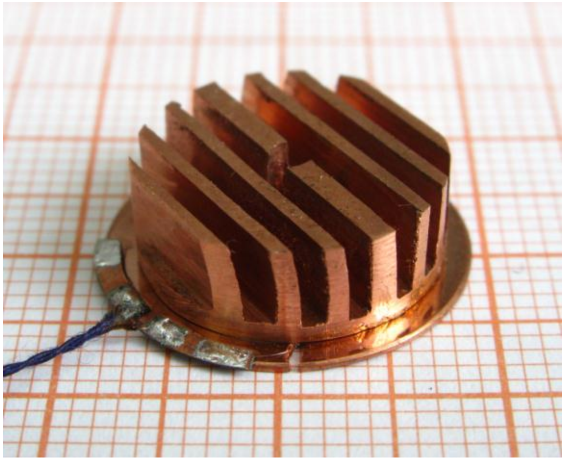
We studied the possibility of using glass-insulated Bi and Bi-Sn microwires to design an anisotropic thermoelectric generator (ATG) and a heat flux sensor (HFS) [1,2]. Glass-coated single-crystal microwires of pure and Sn-doped bismuth were prepared by the Ulitovsky method. Theoretically, in anisotropic thermoelectric crystals, the electric potential is perpendicular to the heat flow and is proportional to the temperature difference of the isothermal faces, the thermopower anisotropy and the crystal length, and inversely proportional to the height of the crystal. An anisotropic thermoelement (AT) can be made from a single-crystal microwire of suitable dimensions without any thermoelectric junctions. Voltage E that arises on the AT outputs is as follows [3]

$$E = S_{12}\Delta T\frac{a}{b} = (S_{33}-S_{11})\sin\alpha\cos\alpha\;\Delta T\frac{a}{b} = (S_{33}-S_{11})\sin 2\alpha\;\frac{1}{2b}\frac{Q_z}{\kappa_{33}\sin^2\alpha + \kappa_{11}\cos^2\alpha} \qquad (1)$$

where $S_{33} - S_{11}$ is the anisotropy of the thermopower, α is the inclination angle of the C_3 crystallographic axes relative to sample axis, ΔT is the transverse temperature gradient, a is the length of the sample, b is the thickness of the sample, Q_z is the heat flux through the AT, κ_{11}, κ_{33} are the thermoconductivity along C_1 and C_3 axes, respectively. For the Bi samples, the maximum sensitivity is achieved at angle α_{opt}=52.8^o. We develop a new technology of recrystallization of glass-insulated Bi and Bi-Sn single-crystal microwires in a high electric field. This technology makes it possible to obtain single-crystal microwires and change the orientation of the main crystallographic C_3 axis along the direction of a high electric field. We have found a new material Bi-0.05at%Sn; at room temperature, it has a high anisotropy of the thermopower of ~60 μV/K, which is 1.5 times higher than the anisotropy of thermopower in pure bismuth microwire. The AT design is protected by the patent of the Republic of Moldova [4]. The experimental samples of ATG and HFS are shown in Fig. 1. When testing the sample by putting the ATG in contact with a surface at 36 ^{o}C (the temperature of human hand) the peak output was a fraction of a volt (210 mV) and the output power is only 2 nW. The sensitivity of HFS is high (s ~ 10-2 V/W); however, the time constant is τ ≈ 0.5 sec. Our devices have slow responses, possibly due to the use of microwires coated with a thick glass layer (t ≈ 7 μm).



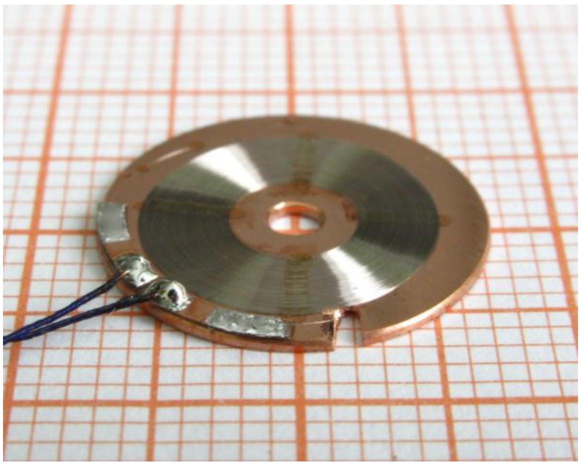


Fig1. Experimental samples of the anisotropic thermoelectric devices. (Left): An ATG made of a long (l≈10 m) glass-insulated single-crystal Bi-0.05at%Sn microwire (D=20 μm, d=4 μm) wound into a flat spiral. At the last stage of preparation of the ATG, a copper radiator was glued on a flat spiral. (Right): HFS made of long (l=9.9 m) glass-insulated single-crystal Bi-0.05at%Sn microwire (D=18 μm, d=4 μm) wound into a flat spiral.

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