Review of Ge-GaAs Thermometers and Multisensors for Measurement of Temperature and Magnetic Field in Cryogenic Applications

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Abstract. This paper reviews the properties of a range of Ge-on-GaAs film resistance thermometers that cover the temperature range 0.03 K to 500 K. A new dual element resistance thermometer is described, in which two temperature sensitive elements with overlapping thermometrical characteristics are combined to provide a thermometer with good sensitivity over the measurement range from 0.1 K to 400 K. A novel dual function sensor for concurrent measurements of temperature from 1.5 K to 400 K and magnetic field is also described. This consists of a Ge-GaAs resistance thermometer and an InSb-GaAs Hall-effect magnetic field sensor combined in a single package.

Keywords: Germanium, thermometers, temperature sensors, magnetic field sensors, multisensors.
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INTRODUCTION

The primary objectives of these developments were: to apply semiconductor and micromachining fabrication techniques to the production of new cryogenic thermometers and multisensors, and to solve three particular problems in cryogenic thermometry, namely: measurement of temperature in the presence of high magnetic fields, thermometer stability in the presence of ionizing radiation, and measurement of temperature with high spatial resolution and fast thermal response time.

GERMANIUM FILM RESISTANCE THERMOMETERS

Ge films on semi-insulating GaAs substrates can be used for production of resistance thermometers covering a temperature range of operation from 0.03 to 500 K [1, 2]. The development of the basic technology for the fabrication of these thermometers has been described by Mitin et al. in Ref. [3]. Typical resistance-temperature dependences for five models of thermometers are shown in Figures 1.

Dual element thermometers (DERTs) have also been designed and produced. These enable measurement of temperature over a wide range, with high sensitivity and resolution over the whole range. This is achieved by incorporating two Ge-film sensor elements in a single package (overall dimensions 3.5 mm wide, 2.2 mm high and 10.1 mm long). The two sensor elements have high sensitivities but over different, overlapping, temperature ranges, so that by selection of the appropriate element the DERT thermometer provides high sensitivity from ultralow to high temperatures.

Thermometer reading errors caused by a magnetic field can be presented as the ratio $\Delta T/T$, where $\Delta T = T(B) - T$, T is the temperature measured at magnetic field $B = 0$, and $T(B)$ is the temperature indicated at magnetic field B. The magnetic field dependent temperature errors for some models of Ge-on-GaAs film thermometers are shown in Table 1 as functions of field and temperature. The data for TTR-G and TTR-D sensors in Table 1 are taken from Ref. [2].

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TABLE 1. Temperature Errors, $\Delta T/T_0$ (%), as a Function of Magnetic Field and Temperature

Model	Temperature (K)	Magnetic field induction (T)				
		2.5	**4**	**6**	**8**	**14**
TTR-G	0.5	0.43	–1.74	–3.65	–6.2	-
	1.0	0.0	–0.3	–0.8	-	-
	2.1	–0.82	–2.8	–6.8	–11.1	–24.1
	4.2	–0.4	–1.0	–2.7	–4.7	–12.5
	77.4	–0.13	–0.21	–0.3	–0.45	–2.0
TTR-D	0.1	63.9	66.7	69.5	-	-
	0.3	0.5	–0.55	–1.0	-	-
	4.2	–5.0	–8.1	–12.0	-	-
TTR-M	4.2	0.5	0.37	–0.44	–2.0	-

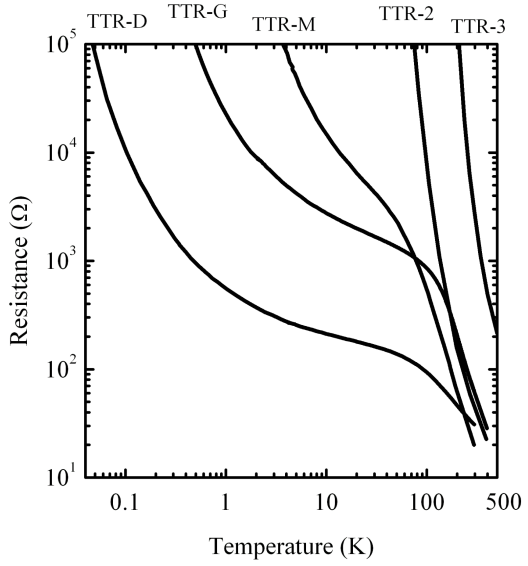

FIGURE 1. Resistance versus temperature curves for Ge-on-GaAs film thermometers of different models.

DUAL FUNCTION SENSORS

The main aims for development of the dual function sensor (DFS) for temperature and magnetic field measurements were to provide simultaneous measurements of temperature and magnetic field and to improve the accuracy of temperature measurements in high magnetic fields by using a correction method based on knowledge of the field sensitivity of the thermometer.

The DFS comprises a Ge-on-GaAs film resistance thermometer and an InSb-on-GaAs film Hall-effect magnetic field sensor combined in a single package. At constant current the Hall sensor provides an output voltage proportional to magnetic field induction. The Hall sensor characteristics are listed in Table 2.

For the temperature sensing elements of the DFS we have used TTR-D, TTR-G and TTR-M devices (Figure 1), providing measurements in the 0.1 K to 400 K, 1 K to 400 K and 4 K to 400 K ranges, respectively.

The dimensions of the DFS package are 3.5 mm wide, 2.2 mm high and 10.1 mm long. The DFS has eight copper contact leads: four leads for the thermometer and four leads for the Hall-effect magnetic field sensor.

TABLE 2. InSb-on-GaAs film Hall Sensor Characteristics

Operating temperature range (K)	1 to 400
Input resistance (Ω)	10 to 20
Output resistance (Ω)	15 to 30
Rated control current at 4.2 K (mA)	0.5
Magnetic sensitivity at 0.5 mA (mV/Tesla)	5 to 6
Zero field offset voltage, max (mV)	0.1
Temperature coefficient of magnetic sensitivity, max (%/K)	0.03

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