Ceramics International 50 (2024) 25779–25791

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

Formulation and optimization of copper selenide/PANI hybrid screen printing ink for enhancing the power factor of flexible thermoelectric generator: A synergetic approach

Ramakrishna Nayak [a], Prakasha Shetty [b,c,*], Selvakumar M [b], Ashok Rao [d], Sriram K V [a], Shivananda Wagle [e], Sandeep Nayak [a], Vinod Kamath [a], Nakul Shetty [f], Mohammad Saquib [b]

[a] Department of Humanities and Management, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, 576104, Karnataka, India
[b] Department of Chemistry, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, 576104, Karnataka, India
[c] Department of Chemistry, Alva's Institute of Engineering & Technology, Moodbidri, 574 227, Karnataka, India
[d] Centre for Clean Energy, Department of Physics, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, 576104, Karnataka, India
[e] Research & Development, Manipal Technologies Ltd, Manipal, Karnataka, 576104, India
[f] Department of Electronics and Communication Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, 576104, Karnataka, India

ARTICLE INFO

Handling Editor: Dr P. Vincenzini

Keywords:
Thermoelectricity
Power density
Cu_3Se_2
Polyaniline (PANI)
Hybrid ink
Screen printing

ABSTRACT

The stunning thermoelectric behavior of inorganic/organic hybrids and the lack of information on screen-printed flexible thermoelectric generators based on Cu_3Se_2 and Polyaniline for low-temperature applications have motivated this work. The synergic influence of various acid dopants, concentration, and annealing temperature of polyaniline on the power density of Cu_3Se_2/PANI ink-based flexible thermoelectric generator is explored. The presence of 1.5 wt% of H_2SO_4-PANI, annealed at 60 °C, decreased the bandgap and electrical resistance of Cu_3Se_2 by 11.96 % and 29.4 %, respectively. As a result, an increase of 46.06 % in the Seebeck coefficient and 242 % in the power output is achieved, which is many folds higher than the few reported works using novel materials. In addition, the Cu_3Se_2/H_2SO_4-PANI ink-based flexible thermoelectric generator with eight legs exhibited a maximum power output, power density, and power factor of 25.69 nW, 23.79 mW/m^2, and 0.77 nW/m^{2}K^2 at ΔT = 100 °C, respectively under external load.

1. Introduction

A flexible thermoelectric generator (FTEG) works on the principles of the Seebeck effect and converts waste heat into useful electric energy. Therefore, it can power wearable devices such as smartwatches, cardiac pacemakers, smart glasses, and cochlear implants [1]. The attractive features of FTEG are no need for maintenance, absence of moving parts, flexibility, and clean energy conversion technology [2]. Thermoelectric materials are classified as organic, inorganic, and carbon-based materials. Among these, inorganic materials, specifically bismuth [3], antimony [4,5], lead-based tellurides [6,7], and selenides [8–10], have exhibited superior thermoelectric performance at low temperatures. However, because of their low availability, toxicity, high cost, and rigid nature have limited their wide applications in wearable FTEGs [11]. Compared with tellurides, selenium-based materials have become promising thermoelectric materials due to their vast availability and lower toxicity. Several research works have reported successful applications of Cu_2Se [8], SnSe [9], PbSe [10], Ag_2Se [12], etc, in wearable FTEGs. Copper selenide is a promising thermoelectric material [13,14]. With a single crystal structure, it exhibits low lattice thermal conductivity (1.3–1.5 W/mK at room temperature) [15]. Copper selenide shows good film-forming properties [12,15], which makes it suitable for flexible device applications. Copper selenide and its hybrids have exhibited good thermoelectric performance in 300–900 K temperature ranges [1, 15–17]. Structural modification, introduction of defects through ball milling, spark plasma sintering [2], alloying [18], composite formulation [16] with varying stoichiometric compositions [1,12,19], doping with lithium [20] are some of the strategies that have resulted in improved thermoelectric properties of copper selenide.

Conversely, organic conducting polymers such as PEDOT: PS [12,

* Corresponding author. Department of Chemistry, Alva's Institute of Engineering & Technology, Moodbidri, 574 227, Karnataka, India.
E-mail address: dr.shetty15@gmail.com (P. Shetty).

https://doi.org/10.1016/j.ceramint.2024.04.315
Received 18 December 2023; Received in revised form 10 April 2024; Accepted 23 April 2024
Available online 24 April 2024