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INVESTIGATION OF THE THERMOELECTRIC CHARACTERISTICS OF SILICON OXIDE THIN FILMS

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Abstract. In contrast to fossil fuels, which are the primary source of energy, thermoelectric devices—which transform heat into electricity—are thought to be a more environmentally benign option. Transparent oxide conductors and semiconductors, or oxide-based materials, have been researched and used in solar cells and thin-film transistors over the past few decades. However, thermoelectric uses have also been investigated for this class of materials. In this dissertation, amorphous silicon oxide thin films were sputtered on a glass substrate at ambient temperature as the argon and oxygen mixture's oxygen concentration varied. The thermoelectric characteristics were assessed in relation to post-deposition annealing parameters (temperature and duration) and deposition circumstances. These characteristics were examined and linked to the corresponding optical, electrical, morphological, and structural characteristics. The Seebeck coefficient and electrical resistivity at room temperature were −68.6 μVK−1 and 4.7×10^{-2} Ωsm, respectively, for films that were deposited without oxygen and annealed at 300 ºC for 24 hours. Higher oxygen percentages in thin films resulted in extremely low conductivity values, making it impossible to calculate the Seebeck coefficient. For the previously mentioned annealing conditions, the highest power factor attained was 10 μWm^{-1} K^{-2}. Electrical conductivity and the Seebeck coefficient both increased at the same time, primarily as a result of scattering mechanisms that increased the Seebeck coefficient.

Keywords: silicon oxide, Seebeck coefficient, amorphous thin films, annealing, reactive sputtering, oxygen percentage.

Аннотация. В отличие от ископаемого топлива, которое является основным источником энергии, термоэлектрические устройства, преобразующие тепло в электричество, считаются более экологичным вариантом. Прозрачные оксидные проводники и полупроводники, или материалы на основе оксидов, были исследованы и использованы в солнечных элементах и тонкопленочных транзисторах в течение последних нескольких десятилетий. Однако этот класс материалов также может быть использован в термоэлектрических целях. В данной работе тонкие пленки аморфного оксида кремния были нанесены на стеклянную подложку при температуре окружающей среды, при этом концентрация кислорода в смеси аргона и кислорода варьировалась. Термоэлектрические характеристики были оценены в зависимости от параметров отжига после осаждения (температуры и продолжительности) и условий осаждения. Эти

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характеристики были изучены и увязаны с соответствующими оптическими, электрическими, морфологическими и структурными характеристиками. Коэффициент Зеебека и удельное электрическое сопротивление при комнатной температуре составили -68,6 МКВК−1 и 4,7 × 10-2 Омсм соответственно для пленок, которые были нанесены без доступа кислорода и отожжены при 300 ºC в течение 24 часов. Более высокое содержание кислорода в тонких пленках приводило к чрезвычайно низким значениям электропроводности, что делало невозможным расчет коэффициента Зеебека. Для ранее упомянутых условий отжига максимальный достигнутый коэффициент мощности составлял 10 мкВт−1 К-2. Электропроводность и коэффициент Зеебека увеличились одновременно, в основном в результате механизмов рассеяния, которые увеличили коэффициент Зеебека.

Ключевые слова: оксид кремния, коэффициент Зеебека, аморфные тонкие пленки, отжиг, реактивное распыление, процентное содержание кислорода.

Annotatsiya. Asosiy energiya manbai bo'lgan qazib olinadigan yoqilg'idan farqli o'laroq, issiqlikni elektr energiyasiga aylantiruvchi termoelektr qurilmalari ekologik jihatdan qulayroq variant hisoblanadi. Shaffof oksidli o'tkazgichlar va yarimo'tkazgichlar yoki oksid asosidagi materiallar so'nggi bir necha o'n yilliklar davomida quyosh batareyalari va yupqa plyonkali tranzistorlarda tadqiq qilingan va qo'llanilgan. Biroq, bu turdagi materiallar uchun termoelektrik foydalanish ham o'rganilgan. Ushbu dissertatsiyada amorf kremniy oksidi yupqa plyonkalar shisha substratga xona haroratida püskürtüldü, chunki argon va kislorod aralashmasining kislorod kontsentratsiyasi o'zgarib turardi. Termoelektrik xususiyatlar cho'ktirilgandan keyingi tavlanish parametrlari (harorat va davomiylik) va cho'ktirish sharoitlariga nisbatan baholandi. Bu xususiyatlar tekshirildi va tegishli optik, elektr, morfologik va strukturaviy xususiyatlar bilan bog'landi. Kislorodsiz yotqizilgan va 300 ºC haroratda 24 soat davomida tavlangan plyonkalar uchun xona haroratidagi Seebeck koeffitsienti va elektr qarshiligi mos ravishda −68,6 μVK−1 va 4,7 × 10−2 Ωsm ni tashkil etdi. Yupqa plyonkalardagi kislorodning yuqori foizi o'ta past o'tkazuvchanlik qiymatlariga olib keldi, bu esa Seebeck koeffitsientini hisoblashni imkonsiz qildi. Oldin aytib o'tilgan tavlanish sharoitlari uchun erishilgan eng yuqori quvvat koeffitsienti 10 mVt m−1 K −2 ni tashkil etdi. Elektr o'tkazuvchanligi va Seebeck koeffitsienti bir vaqtning o'zida ortdi, bu birinchi navbatda Seebeck koeffitsientini oshiruvchi tarqalish mexanizmlari natijasida sodir bo'ldi.

Kalit so'zlar: kremniy oksidi, Seebeck koeffitsienti, amorf yupqa plyonkalar, tavlanish, reaktiv purkash, kislorod ulushi.

INTRODUCTION.

Finding new, eco-friendly solutions is motivated by environmental issues including global warming and the depletion of energy resources. It was quickly realized that cooling could be achieved by running current through a substance and that heat could be utilized as a source of electricity. The discovery of thermoelectric effects made these applications conceivable. The lack of hazardous residues demonstrates that thermoelectric energy converters are greener options without moving parts. Nevertheless, thermoelectric devices' efficiency is still low and cannot now outperform the well-established energy conversion applications [1-8]. One of the primary causes of low efficiency in thermoelectric devices is the materials used. Therefore, more research is needed on this topic in order to increase efficiency. The next sections outline the principles of thermoelectric effects, thermoelectric transport properties, and the focus on oxide thermoelectric materials in order to provide a comprehensive understanding of the thermoelectrics discipline.

METHOD. The first thermoelectric effect—later dubbed the Seebeck effect was discovered by Thomas Johann Seebeck in 1821, marking the birth of thermoelectrics [9]. This effect is seen in figure 1.1, where a temperature gradient given to a material generates an electrical potential [10]. A current flows as a result of the electronic charge carriers moving from the hot side, where energetic electrons have a long mean free path, to the cool side, where electrons have a short mean free path [8, 10].

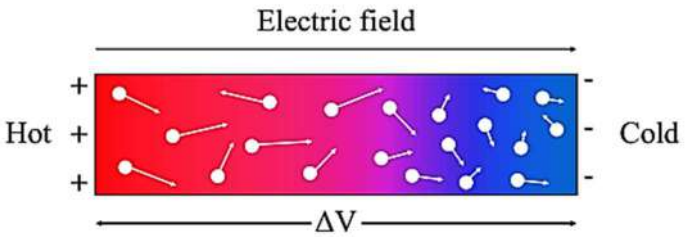


Figure 1.1: Development of an electrical potential as a result of a temperature gradient. Negative charge carriers flow from the hot side to the cold side, inducing an electric field, *E*. Adapted from [11]

A thermocouple, which is made up of wires of two different conductors—typically metals or metal alloys—connected electrically in series and thermally in parallel, is a straightforward method to illustrate this phenomenon. An open electromotive force (emf), which is detectable when a voltmeter is connected, is produced when the connection between the two metals is heated [12]. The temperature differential between the thermocouple junction and the connections to the meter determines this thermoelectric voltage:

$$S_{ab} = \frac{V}{\Delta T}$$

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Where Sab is the differential Seebeck coefficient in V/K under open circuit conditions, V is the electrical potential that appears at both ends, and ΔT is the temperature difference between the two junctions. If a current flows from the heated side to the cold side, the Seebeck coefficient—also known as thermoelectric power, thermopower, or thermal emf—is positive [9].

ELECTRICAL CONDUCTIVITY. One of the most crucial characteristics of a material is its electrical resistivity, or ρ. The electrical conductivity, σ, is the inverse of ρ. Both the electrical conductivity and the Seebeck coefficient are functions of carrier concentration, n, as seen in figure 1.2. In contrast to electrical conductivity, which rises with n, the Seebeck coefficient does not. As will be discussed later, the power factor PF ($S^2\sigma$), which is the product of the square of the Seebeck coefficient and electrical conductivity, maximum at a carrier concentration of around 1019 cm^{-3}, which is typical of semiconductors [12].

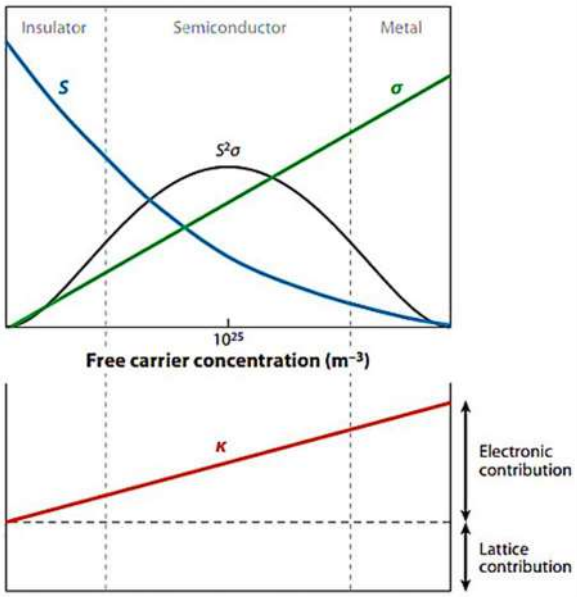


Figure 1.2: Dependence of the Seebeck coefficient, electrical conductivity, power factor, and thermal conductivity on carrier concentration. From [13]

In a semiconductor, it is convenient to express the electrical conductivity by the following expression

$$\sigma = ne\mu$$

Where n is the carrier concentration, μ is the carrier mobility, and e is the charge of unit carrier.

Thermal conductivity. Both an electrical and a thermal component are carried by charge carriers found in metals and semiconductors. Thermal vibrations found in the materials' structures also carry heat [12]. The electronic component, λe, and the lattice component, λL, add up to the total thermal conductivity, λ, as shown by:

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$$\lambda = \lambda_e + \lambda_L$$

The electronic thermal conductivity, λe , is in turn determined by the Lorenz number, L (2.44×10^{-8} WΩK $^{-2}$), given by

$$L = \frac{\lambda_e}{\sigma T}$$

The lattice thermal conductivity, which accounts for only one-third of the overall thermal conductivity, is the primary contribution for a semiconductor [12]. In thermoelectrics, it is convenient for heat conductivity to be as low as possible, as will be seen in the next section. However, as seen in figure 1.2, charge carrier concentration also affects total thermal conductivity. Using phonon scattering, such as phonon-phonon, phonon-defect, and phonon-boundary scattering, is one way to reduce λ [15]. Amorphous structures have lower thermal conductivities.

A thermoelectric material's efficiency is assessed using the figure of merit, or Z. Three physical characteristics are combined in this concept: heat conductivity, Seebeck coefficient, and electrical conductivity. However, as Z changes with temperature, it is typical to represent Z in dimensionless terms by multiplying it by the absolute temperature, T, in Kelvin [12]:

$$ZT = \frac{S^2\sigma}{\lambda}T$$

where S 2σ is the electrical power factor.

Altenkirch did not connect the thermocouple's performance to its thermoelectric characteristics until 1911. A high differential Seebeck coefficient, high electrical conductivities of the two thermoelements, and low thermal conductivities would be required to attain a greater performance [12]. As previously noted, it is challenging to achieve the required ZT values since all of these characteristics—particularly the electrical conductivity and Seebeck coefficient—depend reciprocally on the carrier concentration. The figure of merit optimizes at carrier concentrations characteristic of semiconductor materials, as shown in figure 1.2 [9]. Only the power factor was computed in this work because the thermal conductivity could not be determined.

Thermoelectric materials. Thermoelectric materials include semiconductors, ceramics, oxides, and organic compounds. P F is greater for carrier concentrations typical of semiconductor materials, as seen in figure 1.2. For thermoelectric applications, this family of materials is therefore the most appropriate. Thermoelectric materials are only those whose ZT is greater than 0.5. Once they can be utilized at temperatures up to around 450 K, alloys based on bismuth in combinations with antimony, tellurium, and selenium are the standard materials for commercial thermoelectric refrigeration [9]. With a ZT of about one

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at room temperature, bismuth telluride (Bi_2Te_3) was the best thermoelectric material for a very long time [16]. Similarly, because to their high ZT values, lead telluride and silicon germanium alloys are used in commercial applications for power generation at temperatures as high as 850 K and 1300 K, respectively [9]. It is challenging to simultaneously improve all three transport coefficients, according to the equation. Consequently, low efficiency is a common characteristic of thermoelectric materials. Higher ZT started to be attained by lowering the lattice thermal conductivity as a result of extensive research and development on new classes of materials (skutterudites, clathrates, and Half-Heusler alloys), new structures (quantum wells, quantum wires, quantum dots, and superlattices), and improved mechanisms for improving electronic transport. Furthermore, these solutions pretend to substitute the bismuth-based alloys, once they are expensive and scarse.

CONCLUSION. According to Ioffe's theory, oxide-based materials are not the best thermoelectric options because of ionic bonding with a narrow band in contrast to covalent alloys. Additionally, these materials have high thermal conductivity (about 3–10 Wm^{-1} K^{-1}) and medium electrical conductivity (approximately 100–200 Scm−1), both of which contribute to their low efficiency. Furthermore, mobility and carrier concentration are two or three orders of magnitude lower than those of covalent materials. The majority of the researched thermoelectric materials with similar high performance are poisonous, scarce, and have poor chemical or thermal stability. Conversely, certain oxide-based materials are distinguished by their ease of manufacturing, affordability, excellent chemical and structural stability, and resistance to oxidation.

The overuse of fossil fuels as consumption and population grow is the primary cause of the growing environmental issues of today. Therefore, additional green regulations should be put into place to lessen the adverse effects caused by nonrenewable energy sources. One of the most wasted forms of energy is heat. Since an electrical potential is created when a temperature differential is present, thermoelectric materials can be used in thermoelectric generators to harness this energy source. Oxide materials are being researched extensively for use as transparent conductors, solar cells, TFTs, and sensors. Materials based on indium oxide are very studied in scientific community for electronic applications, namely transparent electronics. In this work, properties of Indium Silicon Oxide thin films were studied, namely the thermoelectric properties. For that purpose, thin films were deposited on glass substrate under different sputtering atmospheres (inert and reactive). The addition of oxygen to the deposition atmosphere led to different growth rates. Although a small oxygen content is usually used to control the film stoichiometry, this addition decreased the growth rate from 11.3 $nmmin^{-1}$ to 7.24

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nmmin^{-1} . Several factor are pointed to this reduction, such as the re-sputtering of the thin film by energetic oxygen anions. Moreover, the low mean free path of the sputtered particles towards the substrate is another pointed factor.

REFERENCES

1. IEA. Renewables Information: Overview 2017. Tech. rep. 2017.
2. IEA. Transforming our World: The 2030 Agenda for Sustainable Development. 2016.
3. E. Commision. Renewable energy - European Commission. https://ec.europa.eu/ energy/en/topics/renewable-energy
4. Y. Orikasa, N. Hayashi, and S. Muranaka. “Effects of oxygen gas pressure on structural, electrical, and thermoelectric properties of $(ZnO)_3$ In_2O_3 thin films deposited by rf magnetron sputtering.” In: Journal of Applied Physics 103.11 (2008), p. 113703.
5. K. Ellmer. “Past achievements and future challenges in the development of optically transparent electrodes.” In: Nature Photonics 6.12 (2012), pp. 809–817.
6. H.-M. Lee, S.-B. Kang, K.-B. Chung, and H.-K. Kim. “Transparent and flexible amorphous In-Si-O films for flexible organic solar cells.” In: Applied Physics Letters 102.2 (2013), p. 021914.
7. S. Aikawa, N. Mitoma, T. Kizu, T. Nabatame, and K. Tsukagoshi. “Suppression of excess oxygen for environmentally stable amorphous In-Si-O thin-film transistors.” In: Applied Physics Letters 106.19 (2015), p. 192103.
8. X. Zheng, C. Liu, Y. Yan, and Q Wang. “A review of thermoelectrics research–Recent developments and potentials for sustainable and renewable energy applications.” In: Renewable and Sustainable Energy Reviews 32 (2014), pp. 486–503.
9. D. M. Rowe. Thermoelectrics handbook : macro to nano. CRC/Taylor & Francis, 2006.
10. K. A. Borup, J. de Boor, H. Wang, F. Drymiotis, F. Gascoin, X. Shi, L. Chen, M. I. Fedorov, E. Muller, B. B. Iversen, and G. J. Snyder. “Measuring thermoelectric transport properties of materials.” In: Energy Environ. Sci. 8 (2 2015), pp. 423–435. doi: 10.1039/C4EE01320D. url: http://dx.doi.org/10.1039/C4EE01320D.
11. Z.-H. Ge, L.-D. Zhao, D. Wu, X. Liu, B.-P. Zhang, J.-F. Li, and J. He. “Low-cost, abundant binary sulfides as promising thermoelectric materials.” In: Materials Today 19.4 (2016), pp. 227–239.
12. H. J. Goldsmid. Introduction to thermoelectricity. Vol. 121. Springer, 2010.
13. A. Shakouri. “Recent developments in semiconductor thermoelectric physics and materials.” In: Annual Review of Materials Research 41 (2011).

ISSN 3030-3907

14. M. Cutler and N. F. Mott. “Observation of Anderson localization in an electron gas.” In: Physical Review 181.3 (1969), p. 1336.
15. C. Han, Z. Li, and S. Dou. “Recent progress in thermoelectric materials.” In: Chinese science bulletin 59.18 (2014), pp. 2073–2091.
16. G. S. Nolas, J. Sharp, and J. Goldsmid. Thermoelectrics: basic principles and new materials developments. Vol. 45. Springer Science & Business Media, 2013.

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